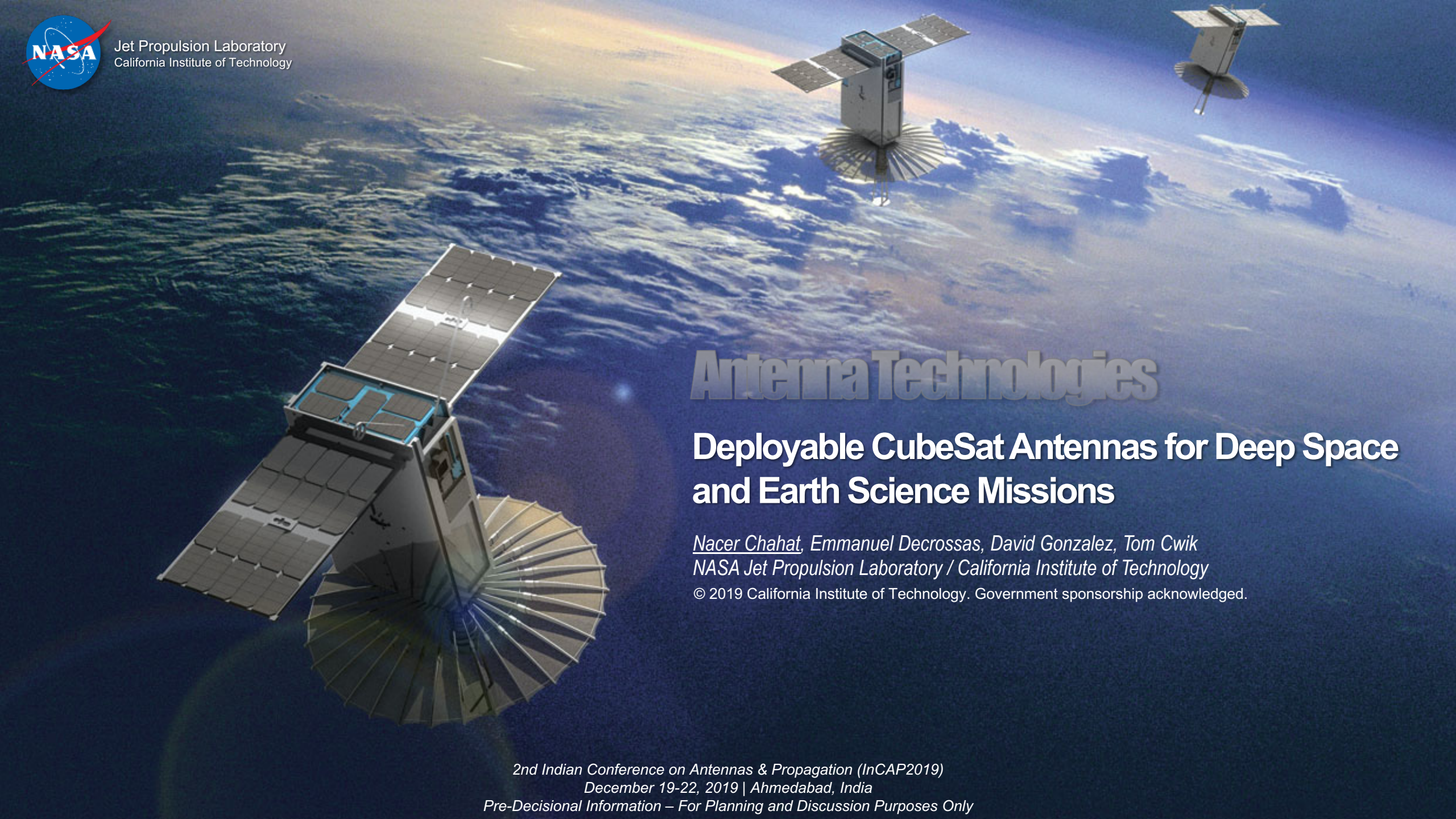


# Deployable CubeSat Antennas for Deep Space and Earth Science Missions

*Nacer Chahat, Emmanuel Decrossas, David Gonzalez, Tom Cwik*
*NASA Jet Propulsion Laboratory / California Institute of Technology*

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*2nd Indian Conference on Antennas & Propagation (InCAP2019)*
*December 19-22, 2019 | Ahmedabad, India*
*Pre-Decisional Information – For Planning and Discussion Purposes Only*

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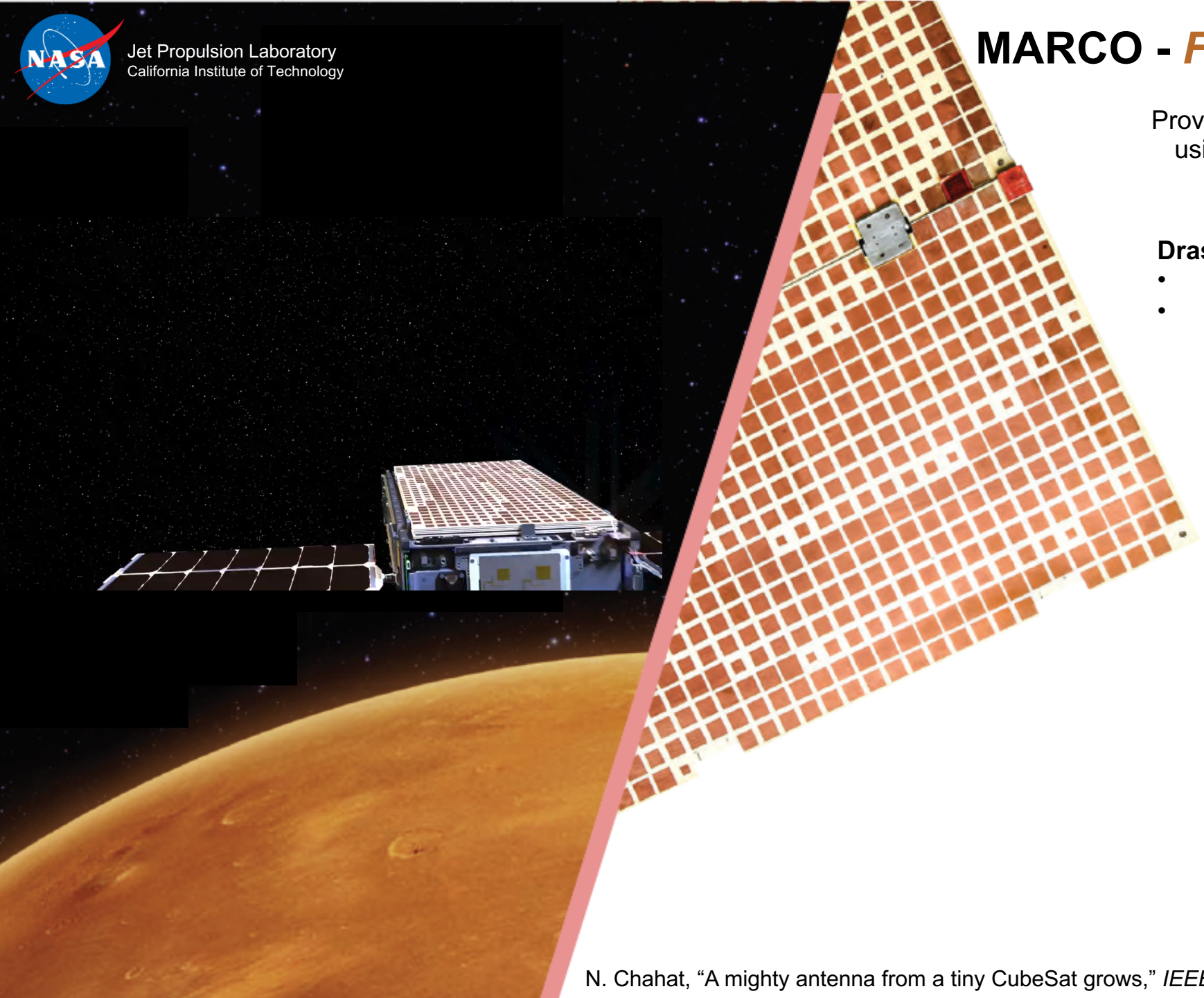
# MARCO - *First Deep Space CubeSat*





Provided bent pipe communication at 1AU at 8kbps using an innovative UHF deployable antenna and the first reflectarray in Space.

**Drastic requirements:**

- Stowage volume: 12.5mm × 210mm × 345mm
- Gain of at least 28dBic (required aperture: 335mm × 587mm)

**Constraints:**

- No internal stowage volume
- Limited RF output power

N. Chahat, “A mighty antenna from a tiny CubeSat grows,” *IEEE Spectrum*, vol. 55, no. 2, pp. 32-37, Jan. 2018.

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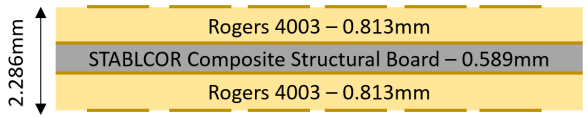
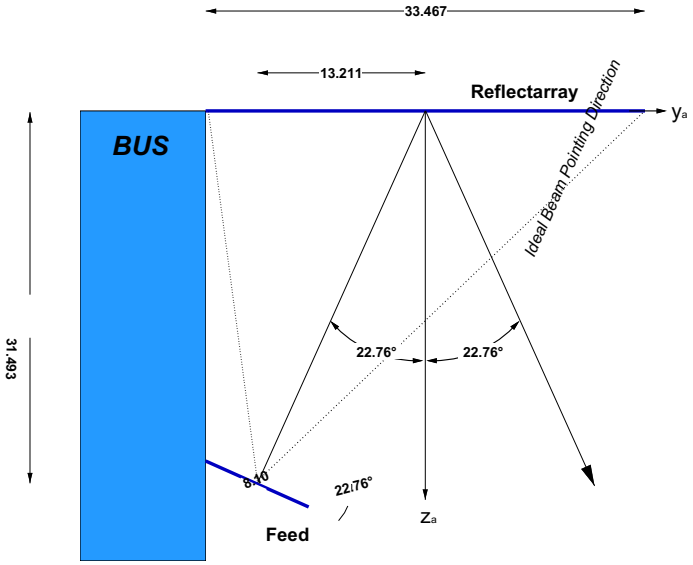
# MARCO - *First Deep Space CubeSat*

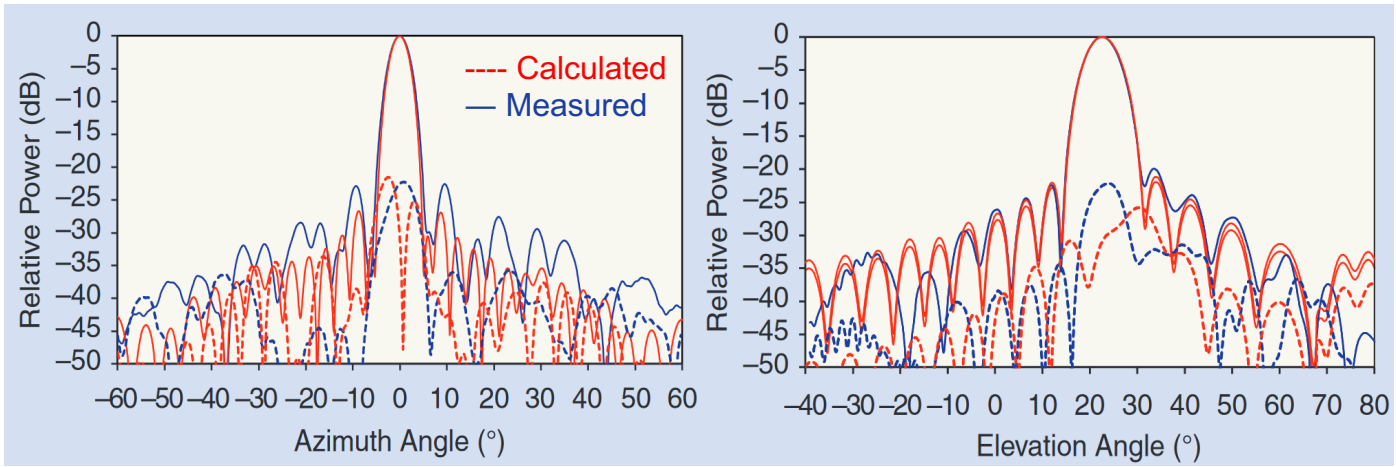
## Reflectarray design:




**Panel configuration**

| | S/N 001 | S/N 002 |
|---|---|---|
| **Computed directivity** | **30.56** | **30.50** |
| Feed loss | –0.74 | –0.74 |
| Patch dielectric loss | –0.25 | –0.25 |
| Patch conductor loss | –0.04 | –0.04 |
| Mismatch loss | –0.14 | –0.14 |
| Hinge mounting area loss | –0.15 | –0.15 |
| **Total loss** | **–1.32** | **–1.32** |
| **GAIN predict** | **29.24** | **29.18** |

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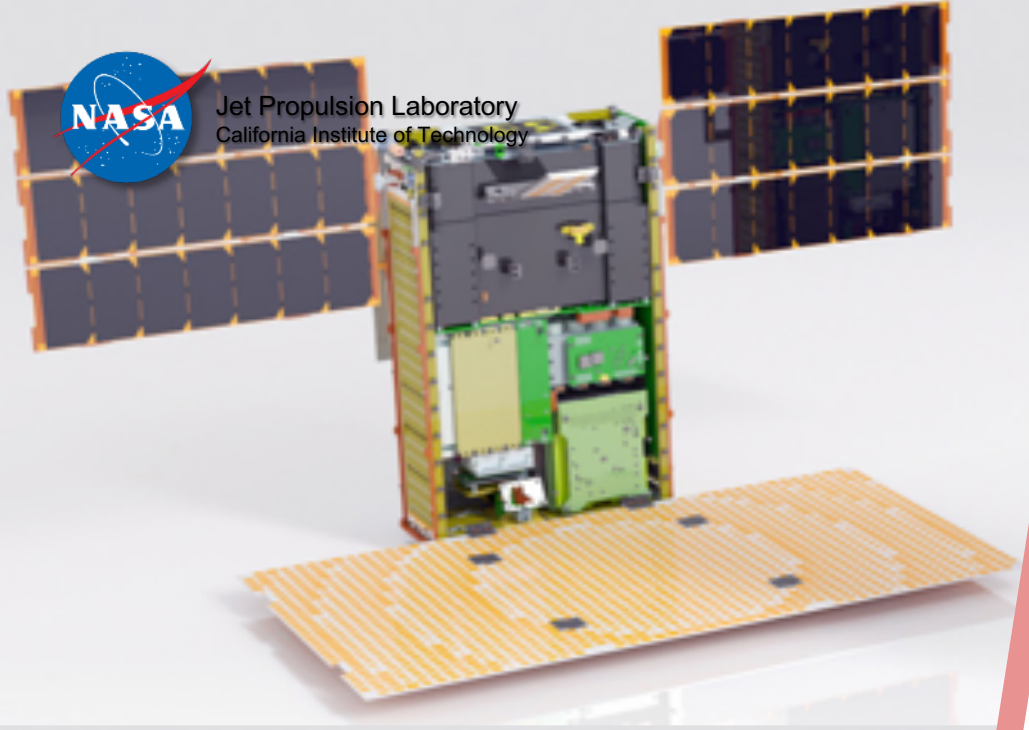


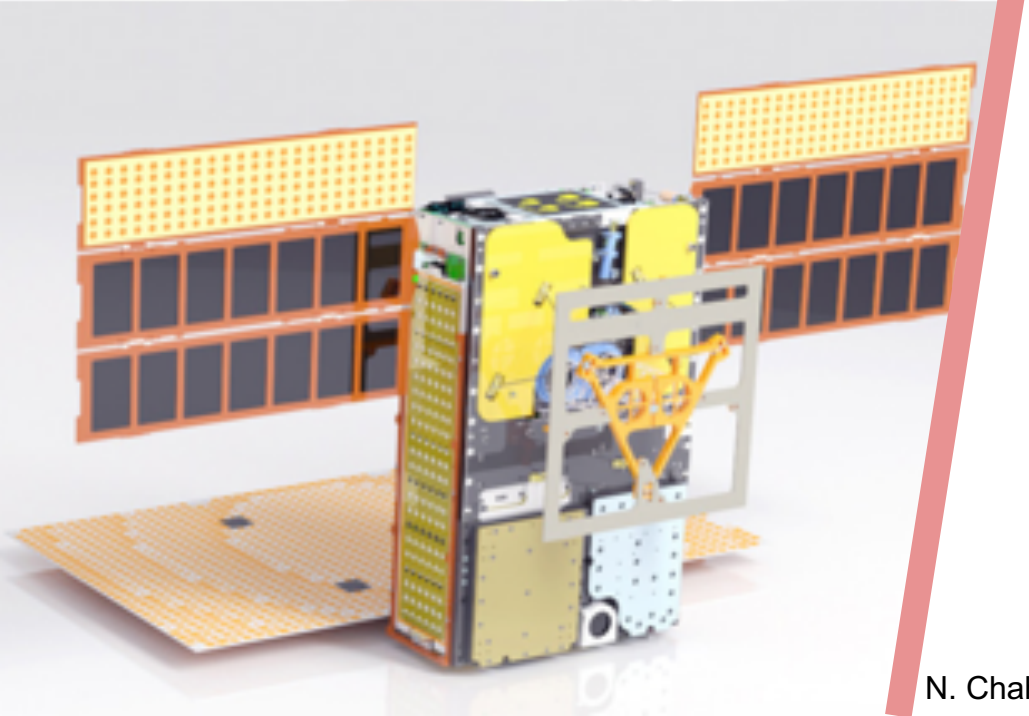

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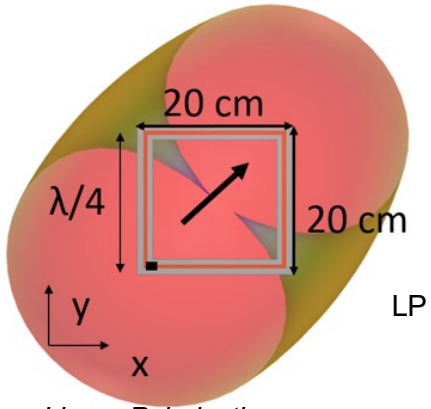
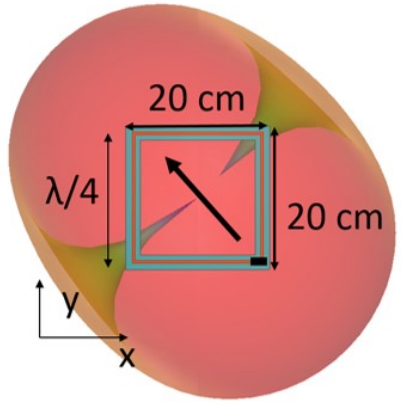
**UHF deployable antenna**: achieving circular polarization with a deployable loop.

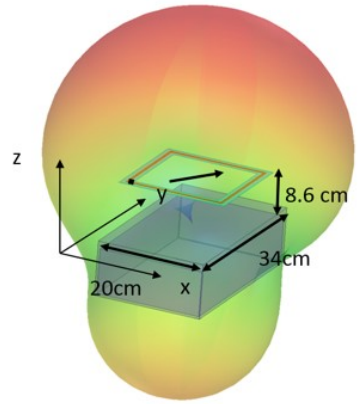



*Linear Polarization*

LP




*Linear Polarization*

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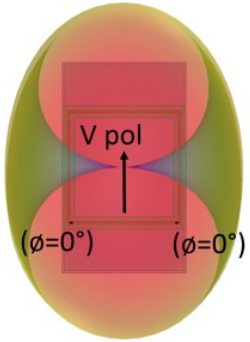


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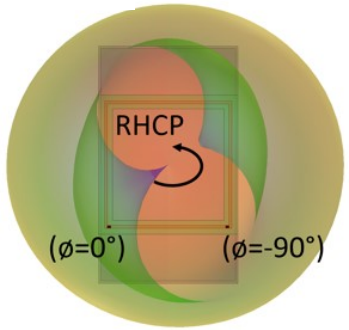
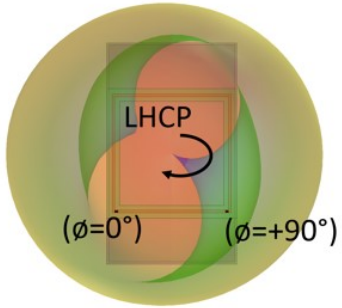
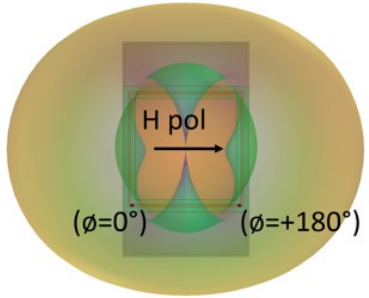



*RHCP*




*LHCP*




*Linear Polarization*

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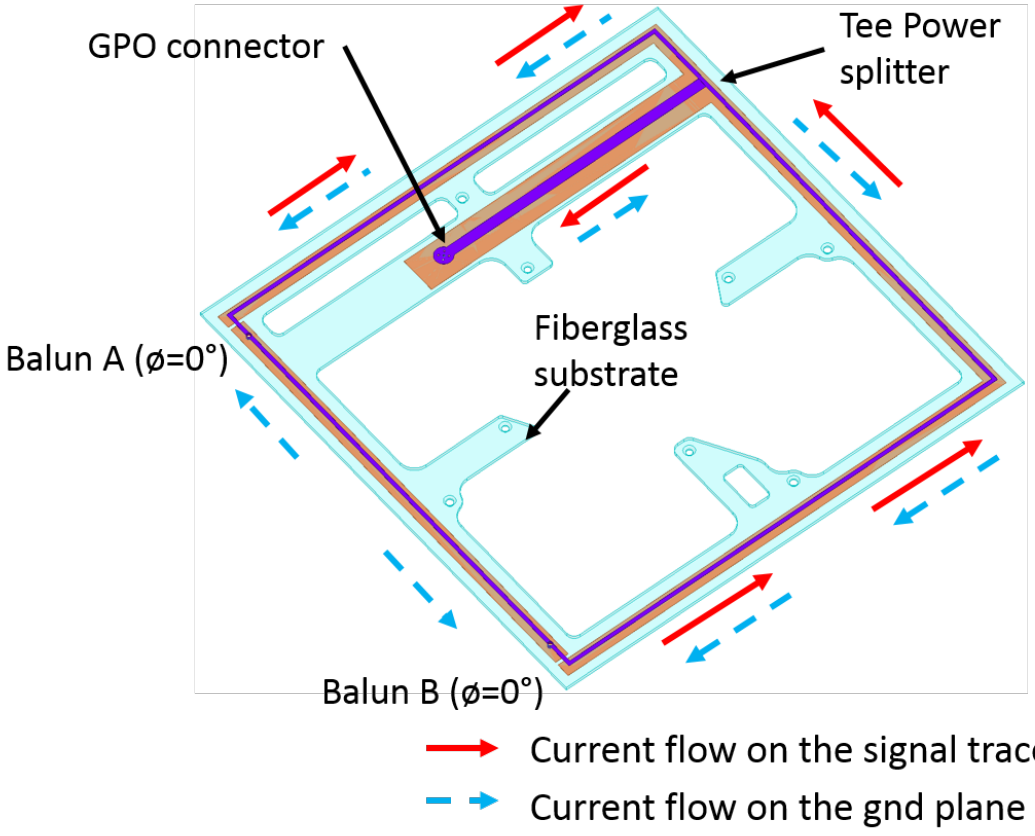


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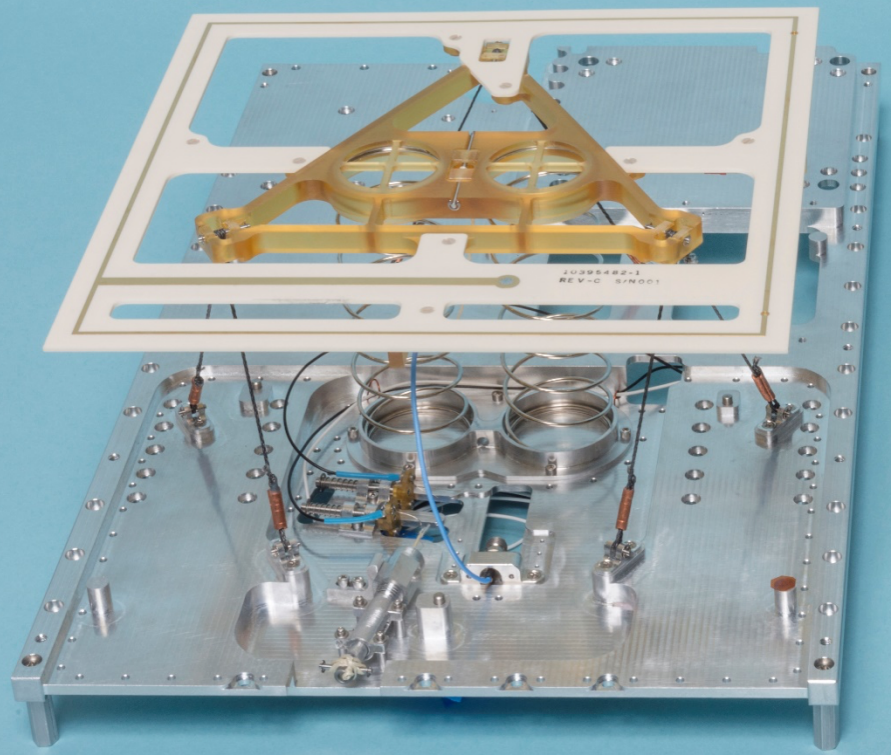

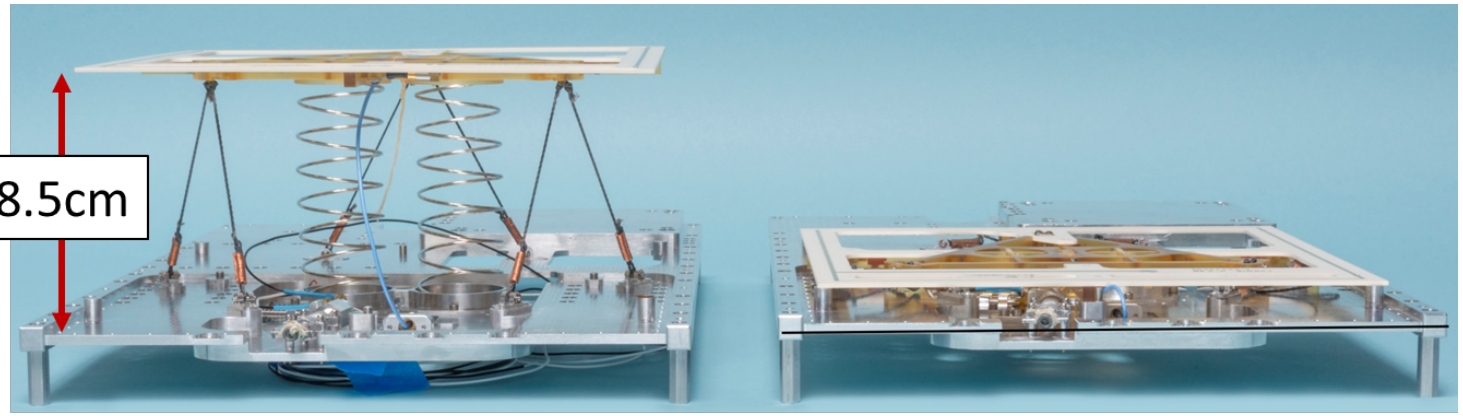


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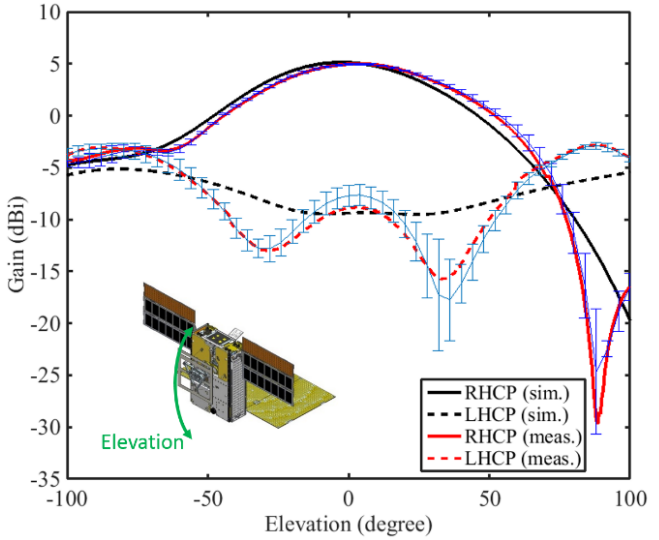


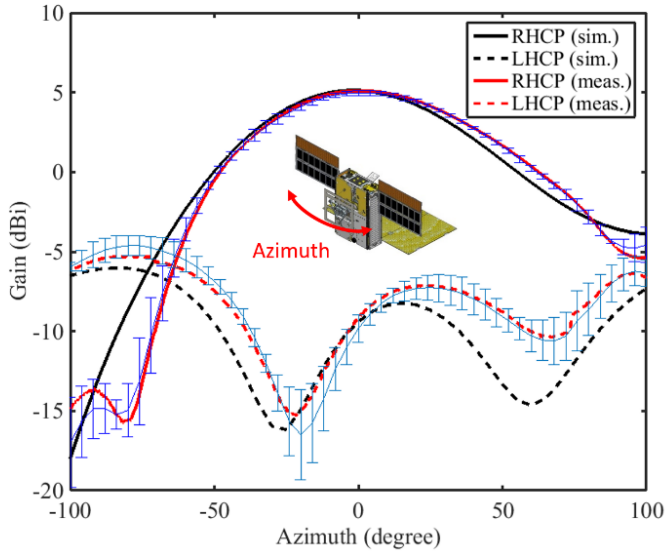


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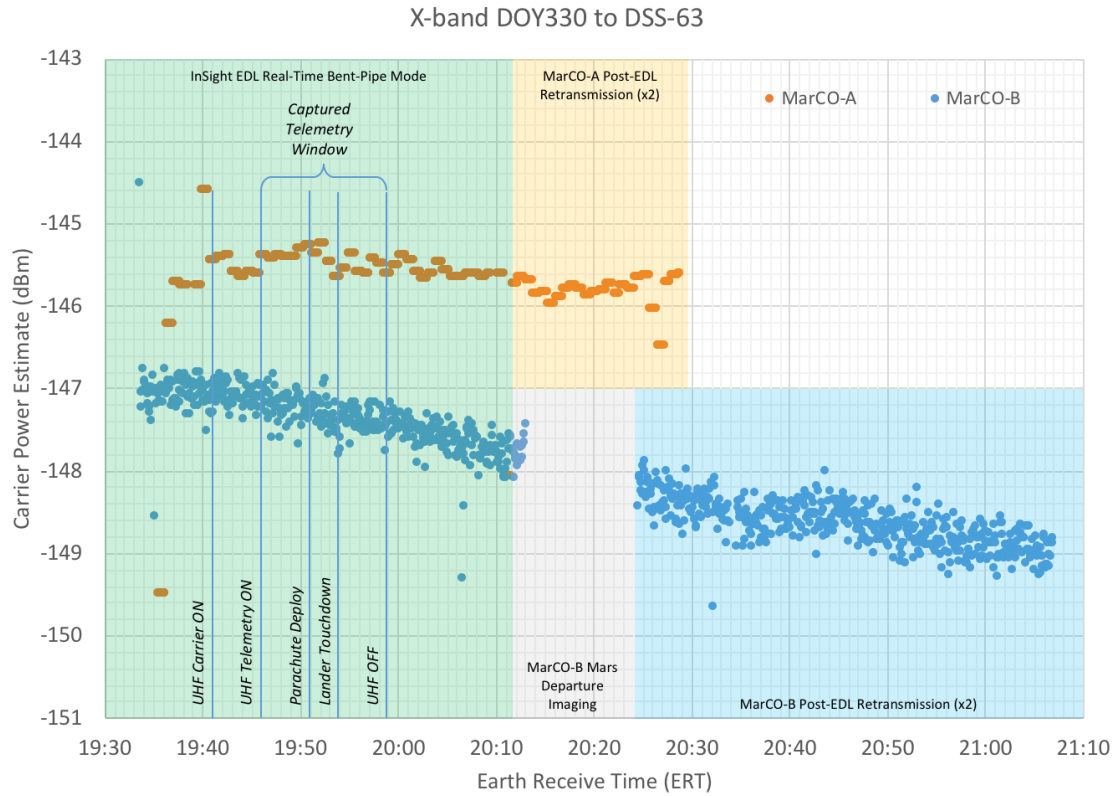
# MARCO - *First Deep Space CubeSat*

- **Reflectarray demonstrated in Space**:
  - Successful deployment of two antennas in space
  - Quick gain assessment has shown that the gain is within ±0.4dB.
  - Pattern successfully verified in space
- **An historical deployment witnessed by a picture of Mars**

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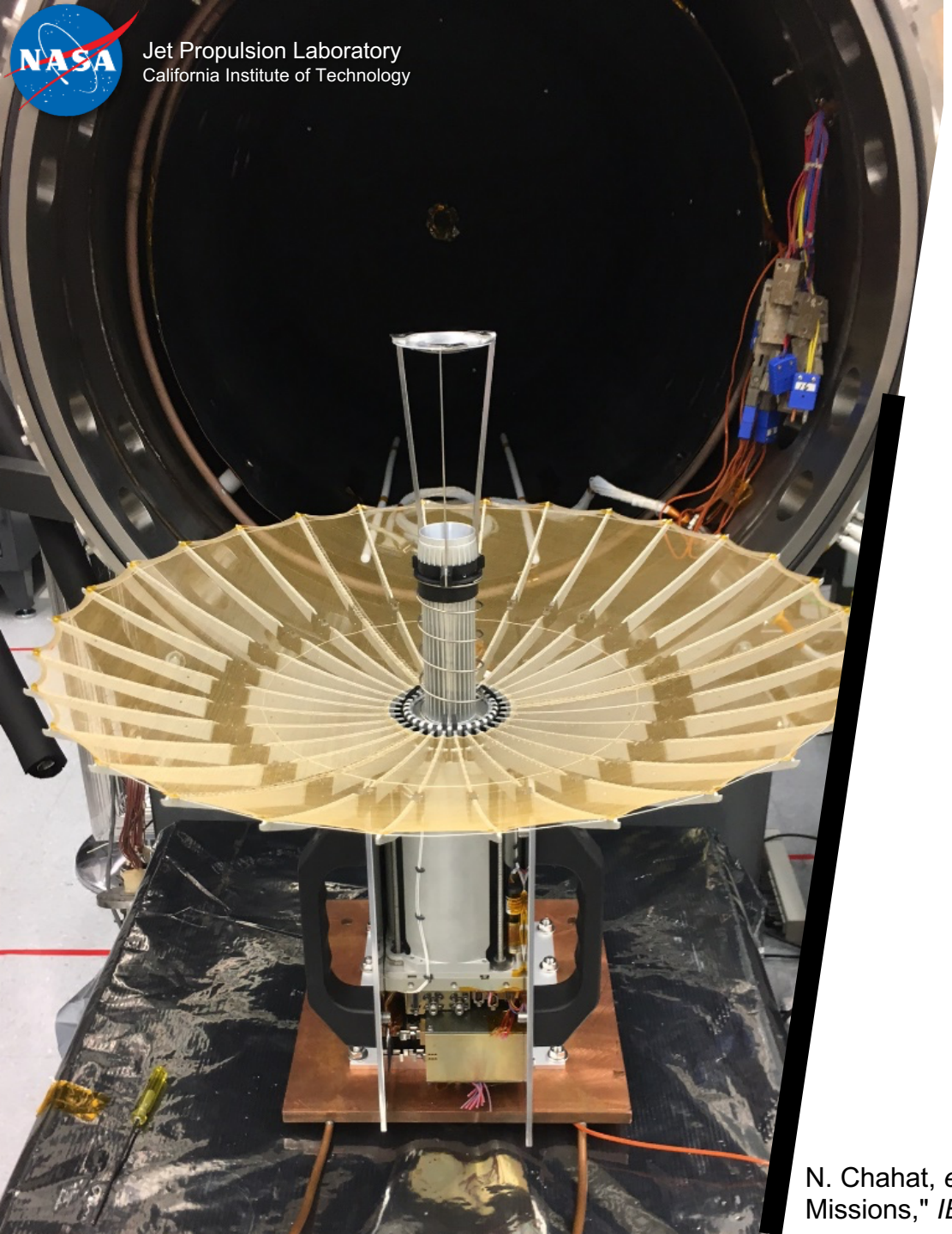
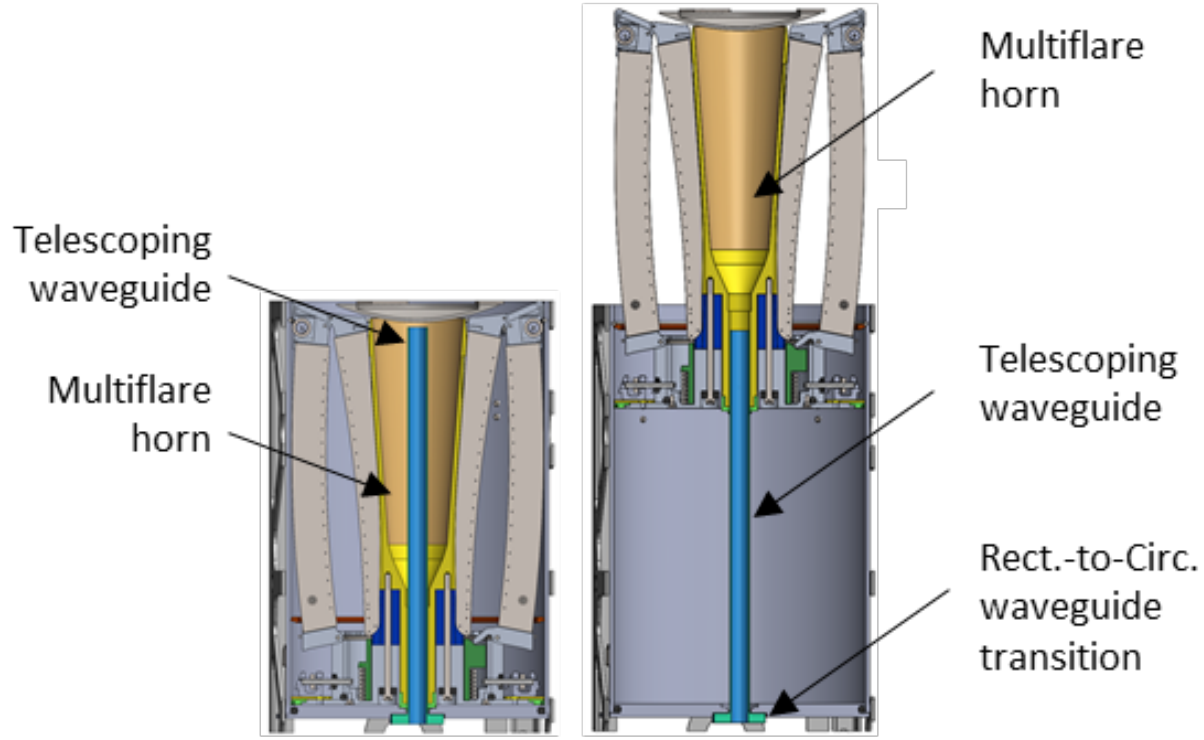



# RAINCUBE - *First Active Radar in a CubeSat*

**Ka-band deployable mesh reflector antenna**:

- 0.5-m reflector Ka-band antenna
- Polarization: V-polarization
- Gain: 42.6 dBi
- Efficiency: 56%




N. Chahat, *et al.*, "CubeSat Deployable Ka-Band Mesh Reflector Antenna Development for Earth Science Missions," *IEEE Trans. Antennas & Propag.*, vol. 64, no. 6, pp. 2083-2093, June 2016.

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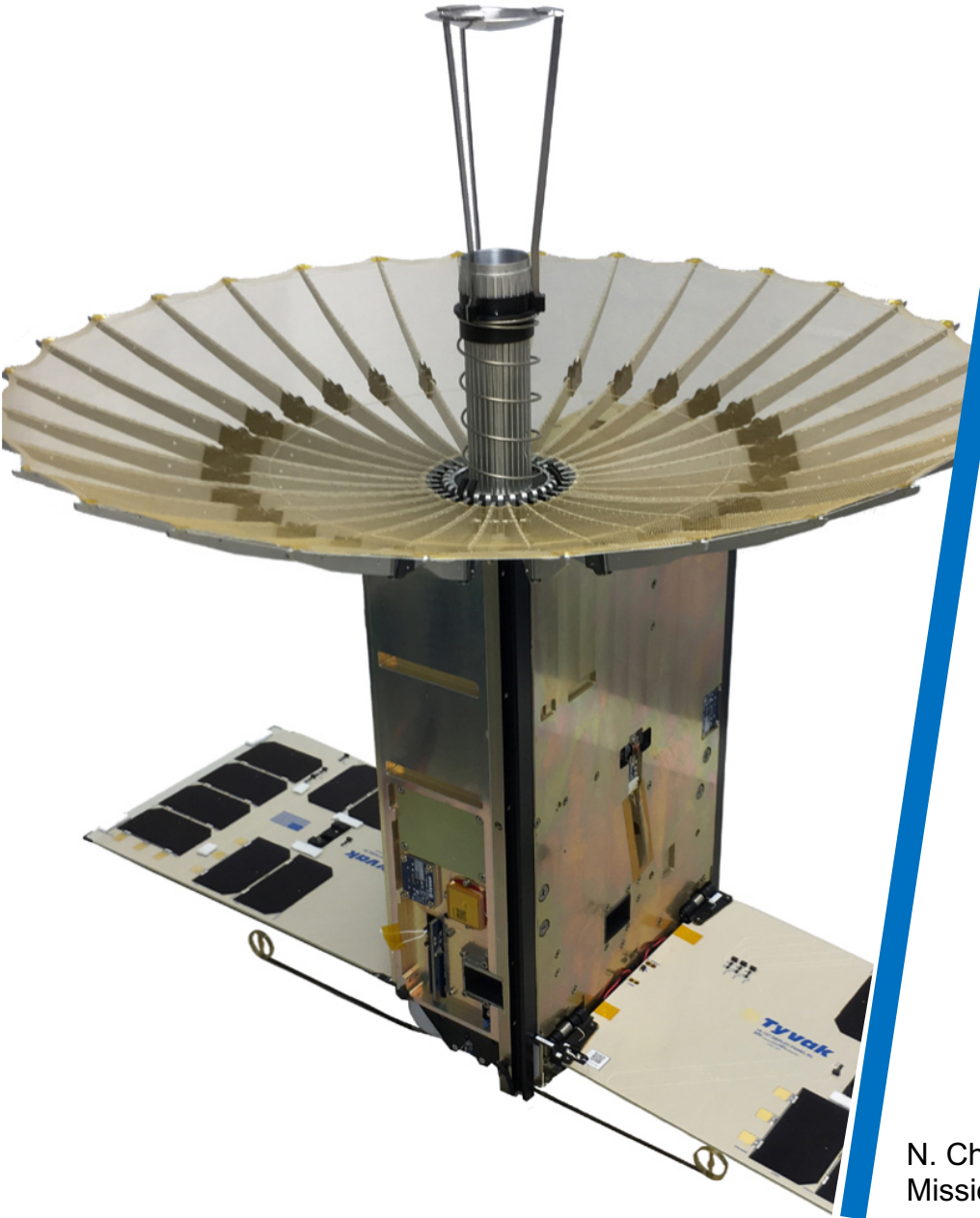

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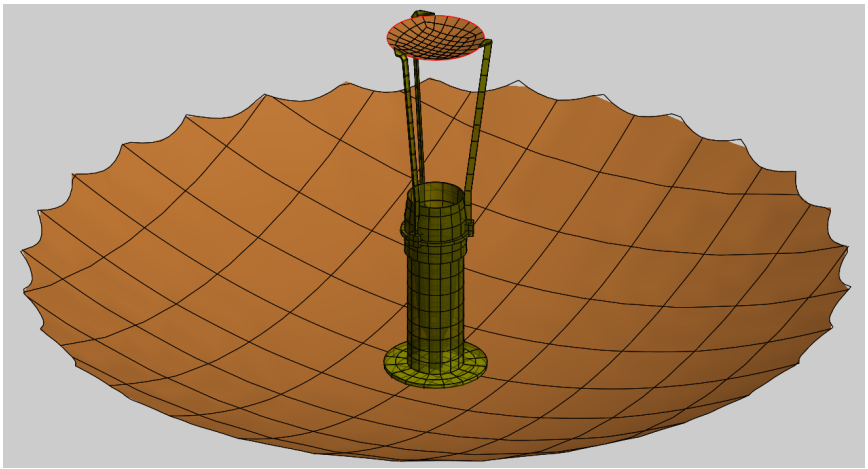

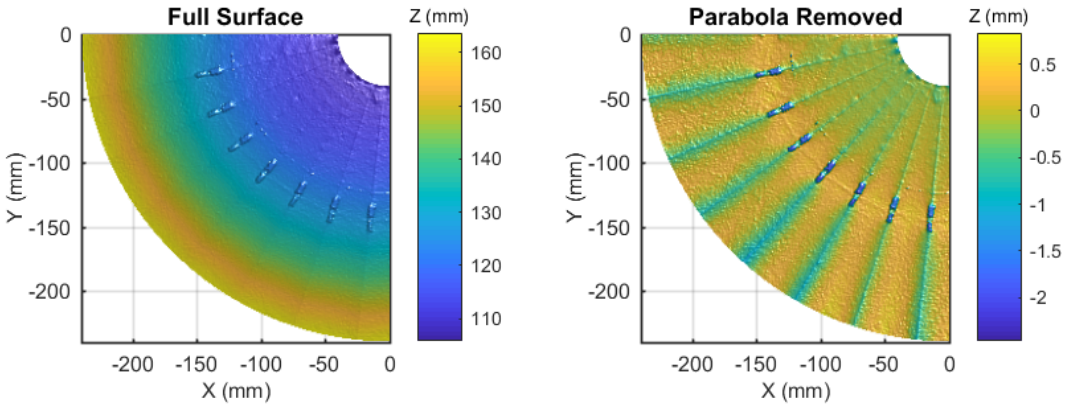


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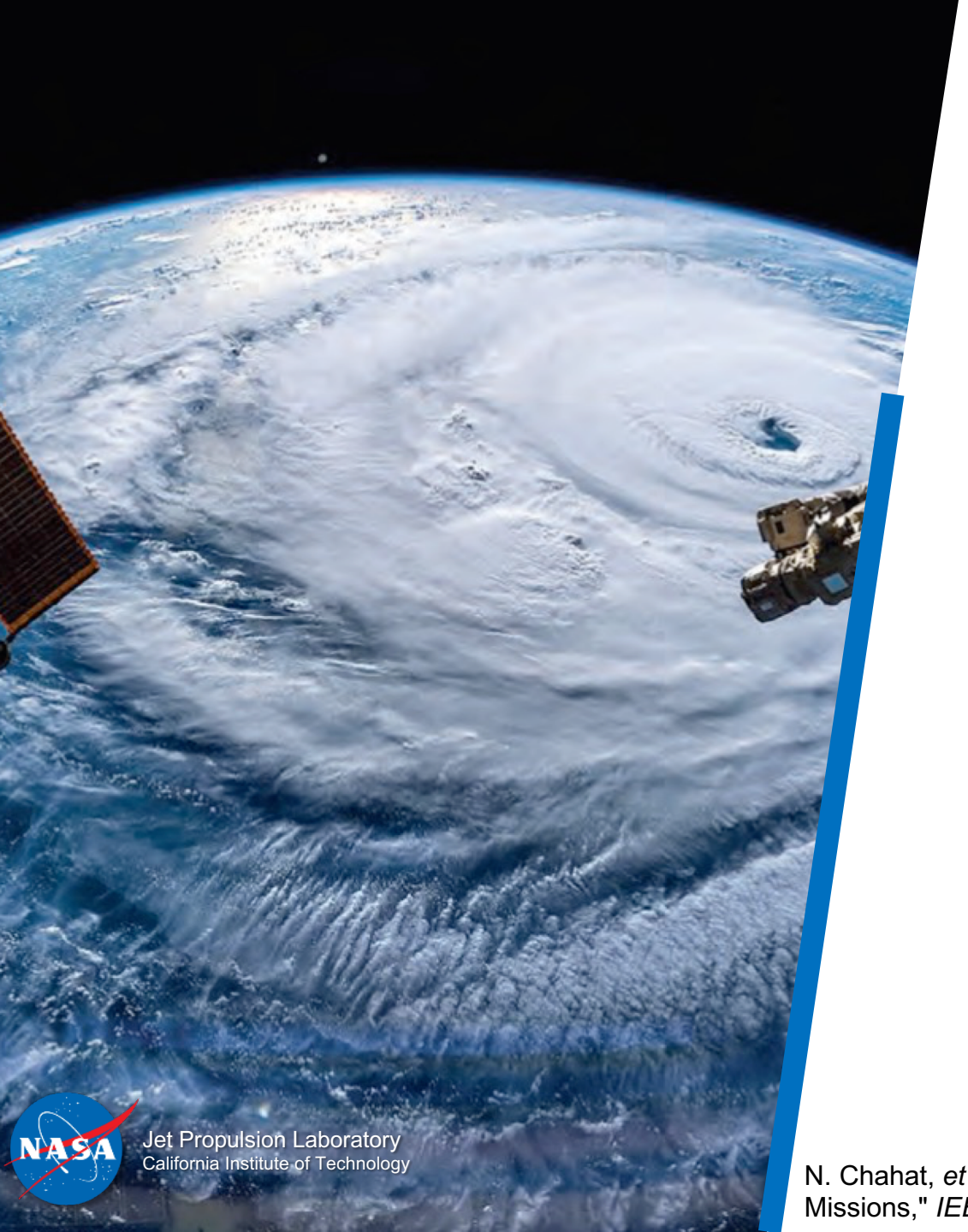

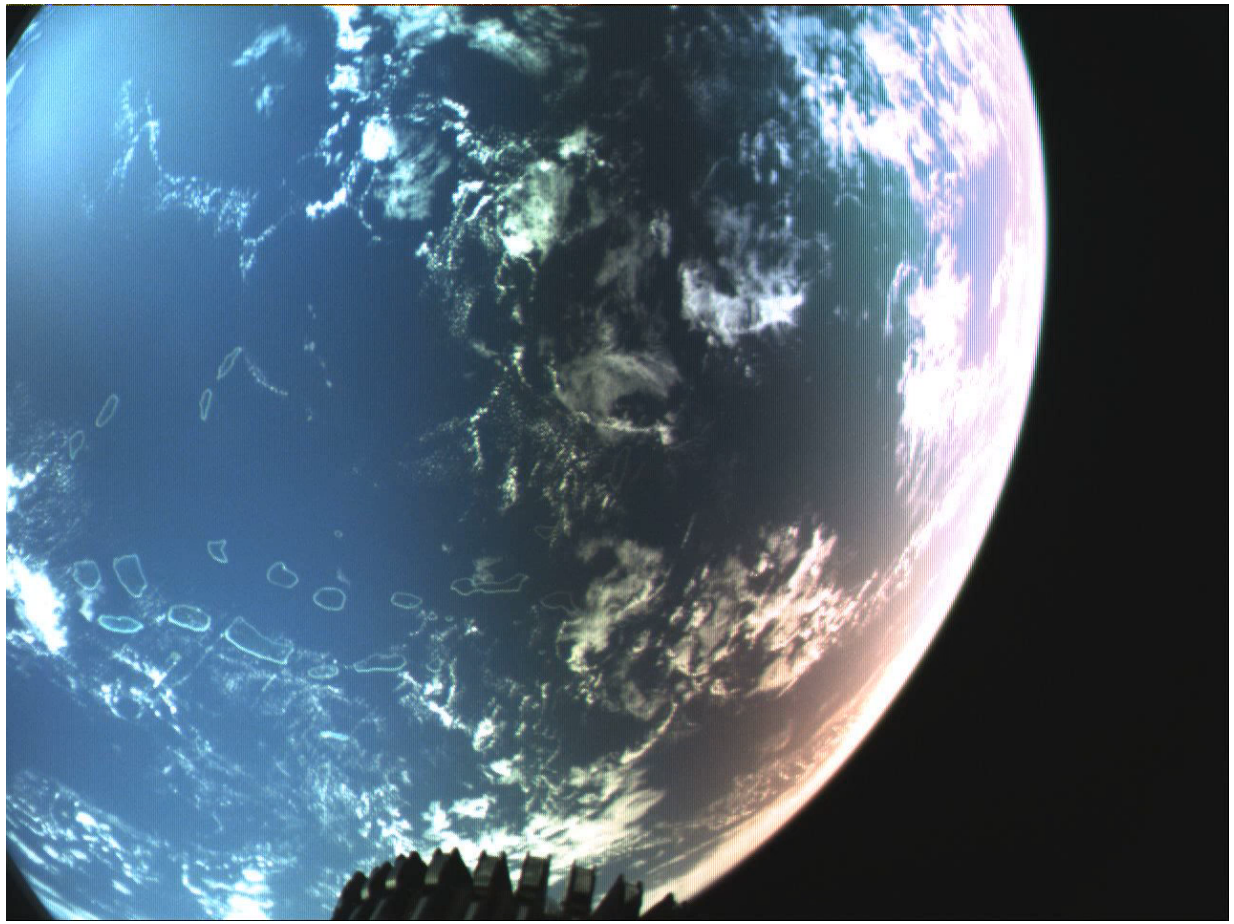

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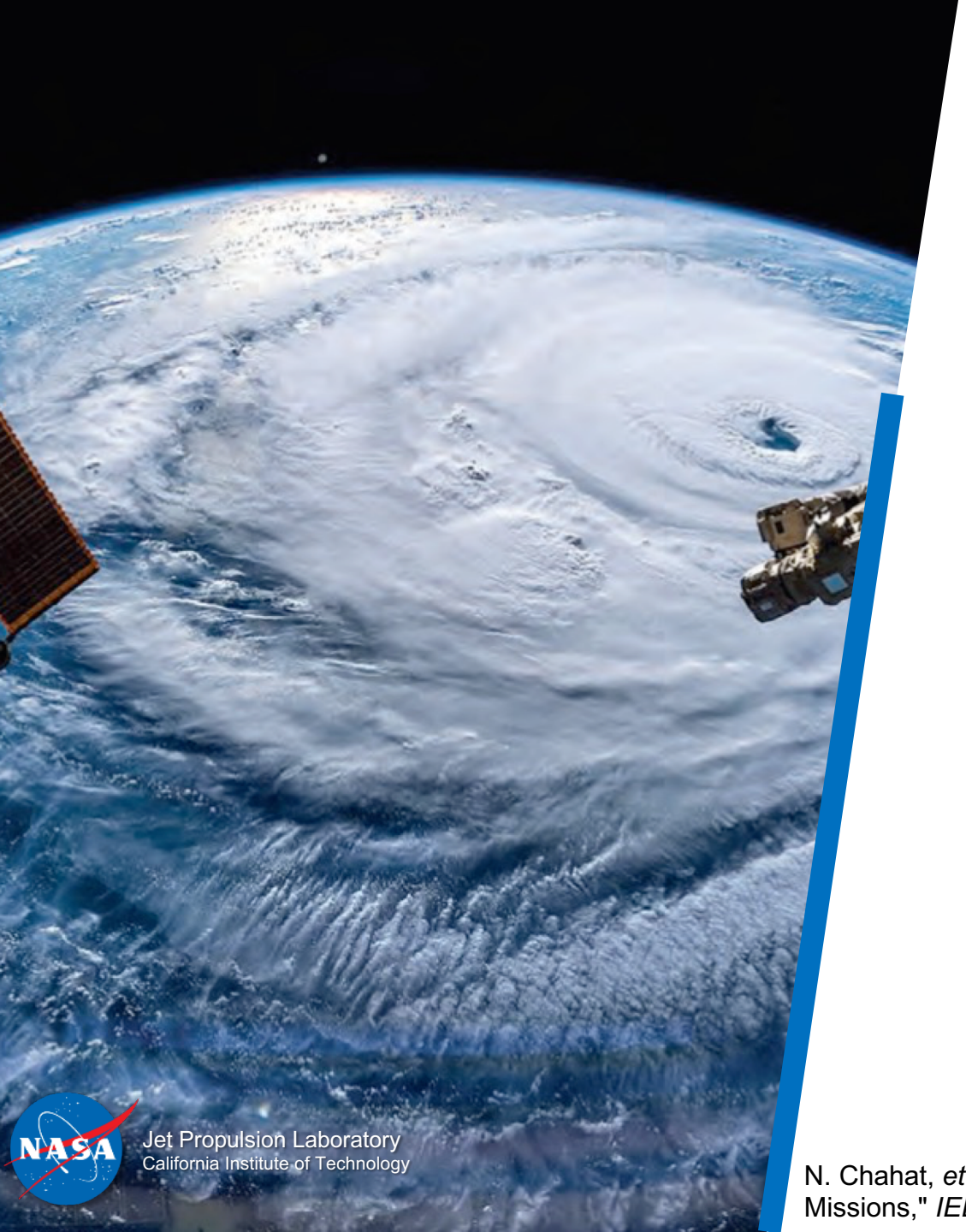

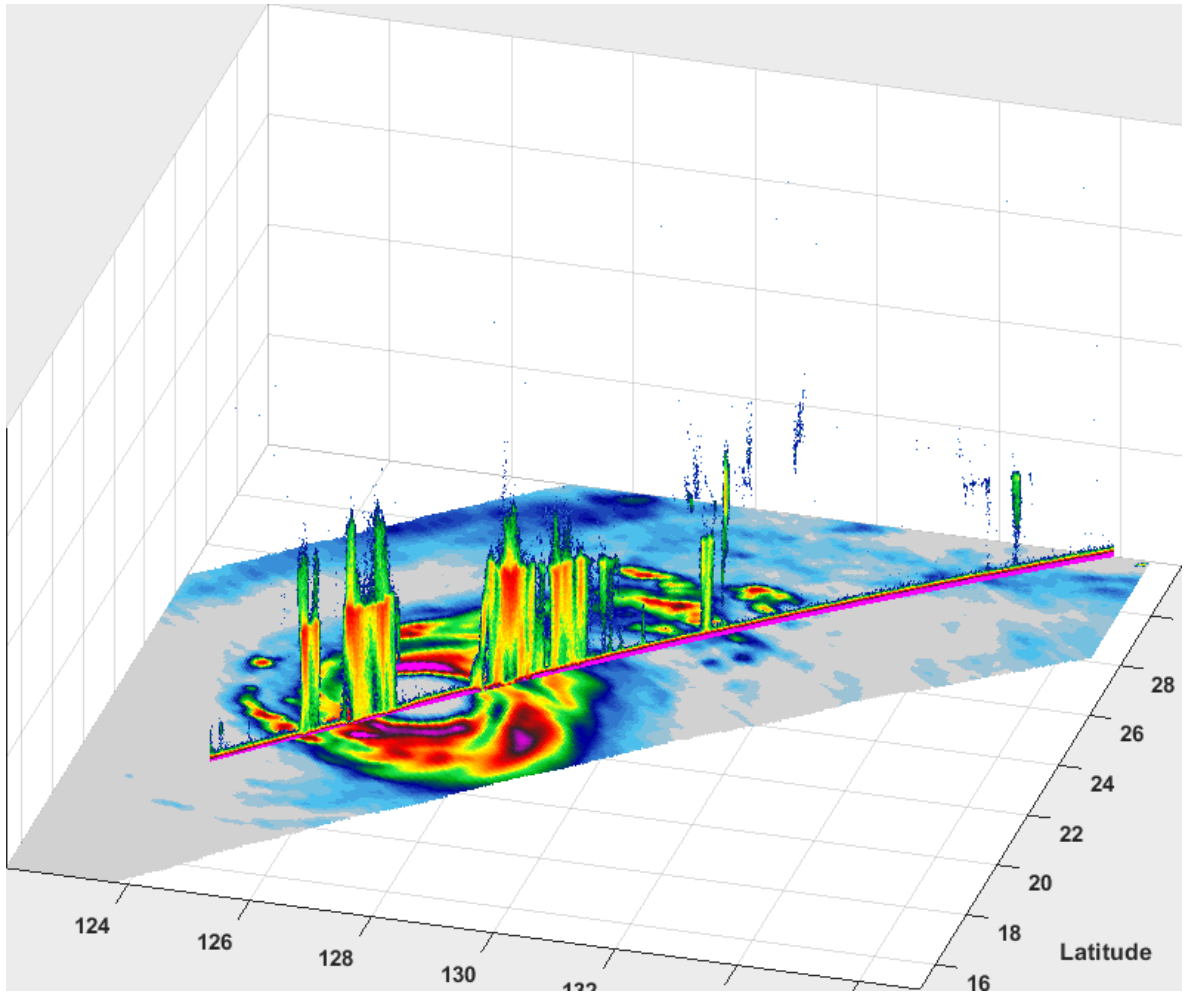


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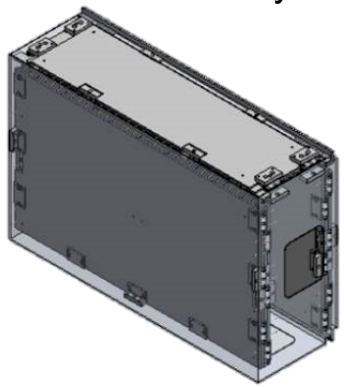
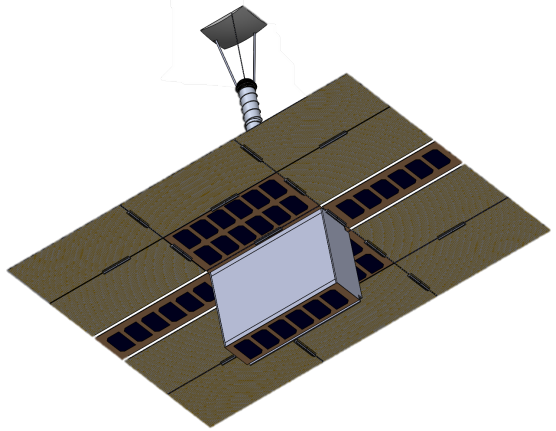
# OMERA – *Larger Deployable Reflectarray*

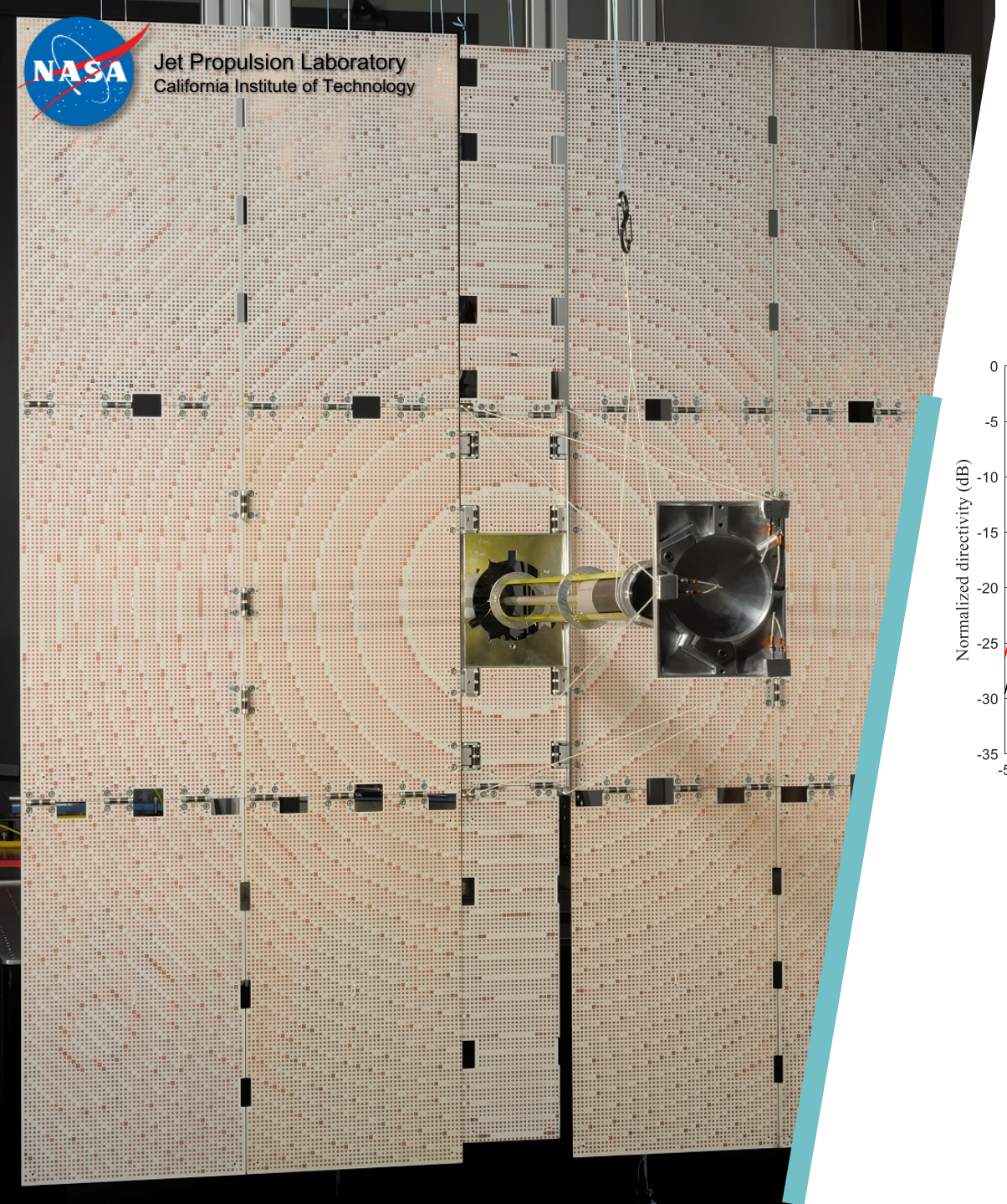
**Ka-band deployable reflectarray**:

- 1-m reflector Ka-band antenna (98.6cm×82.1cm)
- Polarization: V-polarization
- Gain: > 47.0 dBi
- Efficiency: 47%





| | Gain (dBi) | Loss (dB) |
|---|---|---|
| Ideal directivity | 51.58 | - |
| Spillover | 50.67 | 0.91 |
| Taper | 49.95 | 0.72 |
| Blockage | 49.67 | 0.28 |
| Struts | 49.37 | 0.3 |
| Gap loss | 49.22 | 0.15 |
| Patch dielectric / conductivity loss | 48.97 | 0.25 |
| Surface accuracy * | 47.77 | 1.2 |
| Feed loss / telescoping waveguide / transition | 47.47 | 0.3 |
| Feed mismatch (RL=17dB) | 47.38 | 0.09 |
| Overall performance | 47.38 | 4.2 |




# OMERA – *Larger Deployable Reflectarray*

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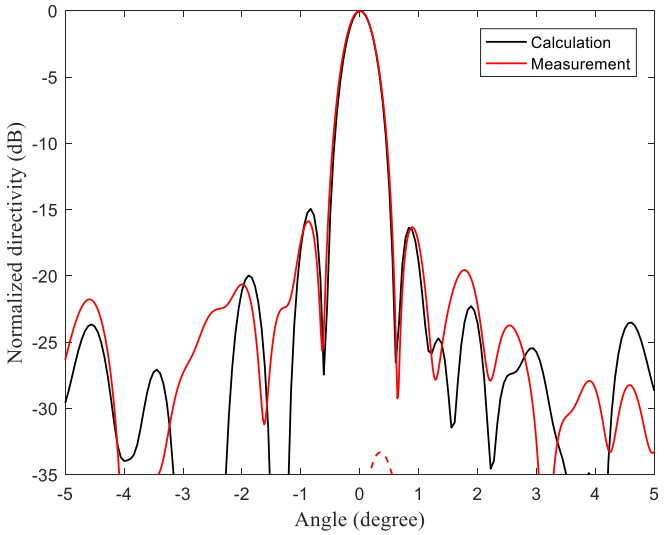


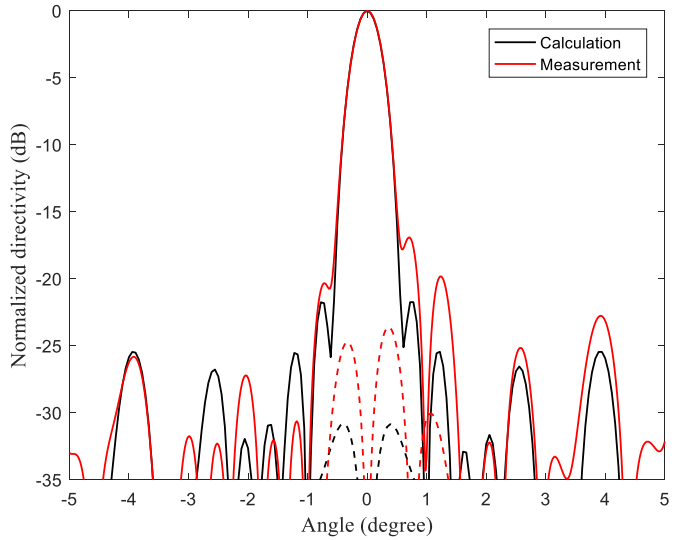


Gain = 47.1dBi at 35.75GHz

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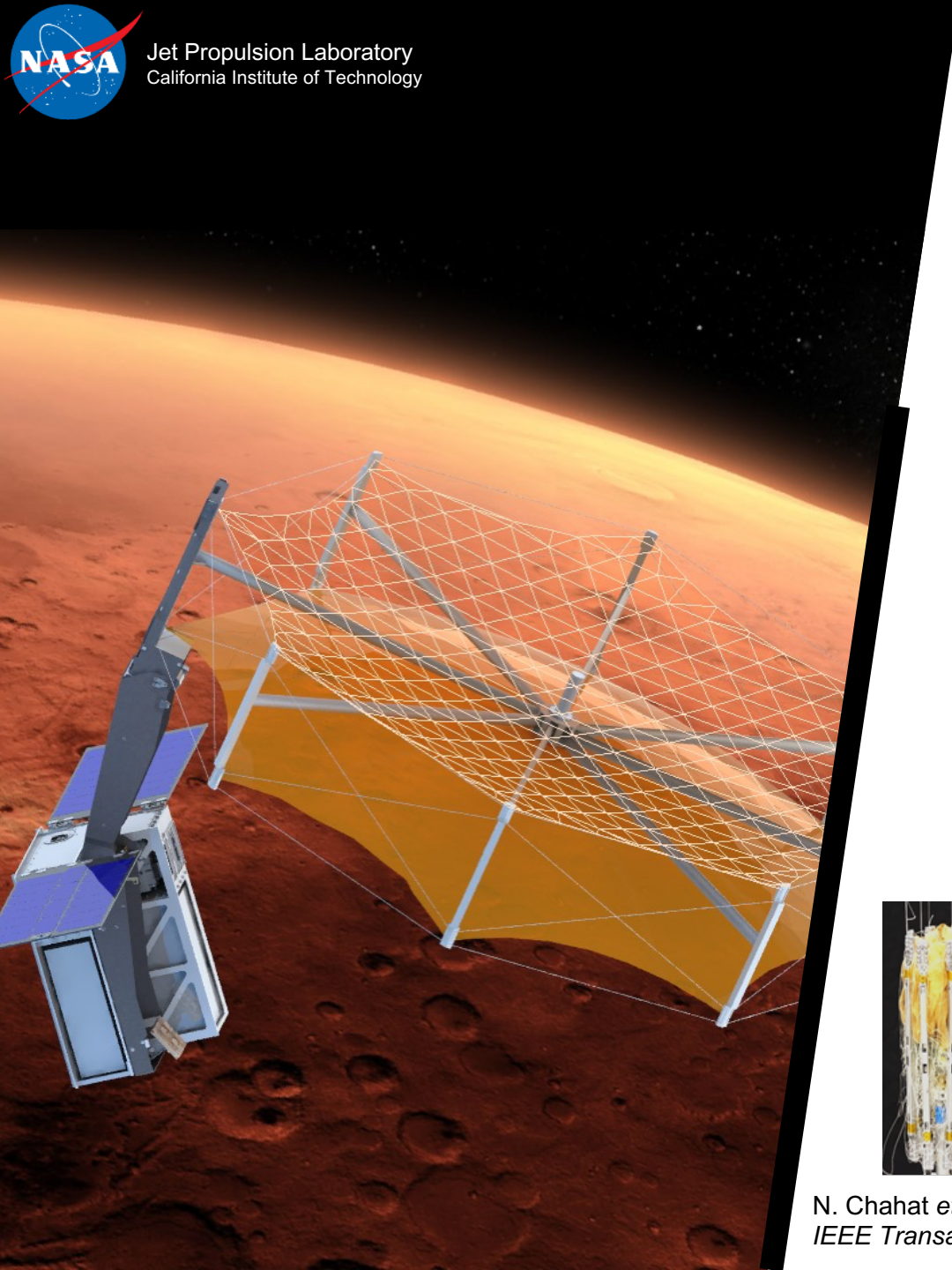
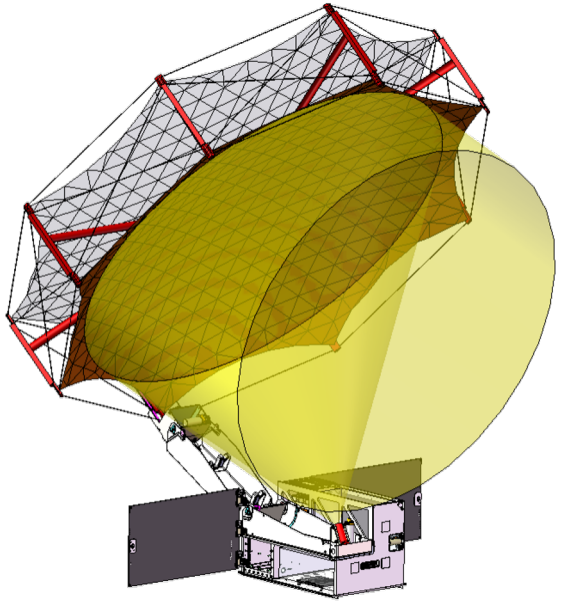
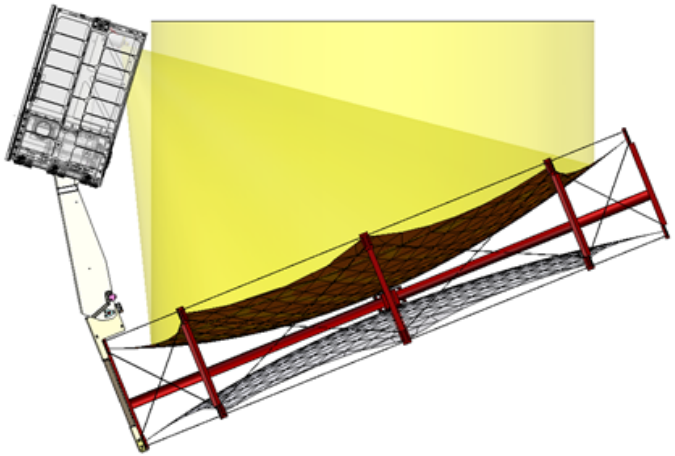


# X/Ka Deployable Mesh Reflector

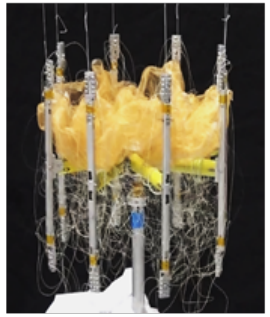
**Ka-band deployable mesh reflector antenna**:

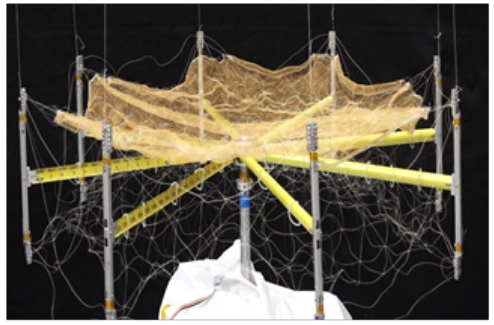
- 1-m reflector Ka-band antenna
- Polarization: RHCP
- Gain: > 36.8 dBic at X-band and 48dBic at Ka-band
- Efficiency: 62% at X and Ka-band

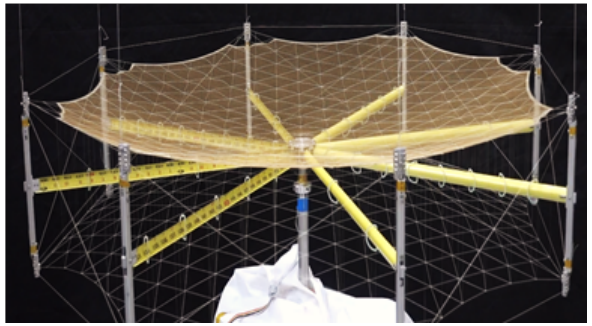












N. Chahat *et. al*, "One-Meter Deployable Mesh Reflector for Deep Space Network Telecommunication at X- and Ka-band," in *IEEE Transactions on Antennas and Propagation*.

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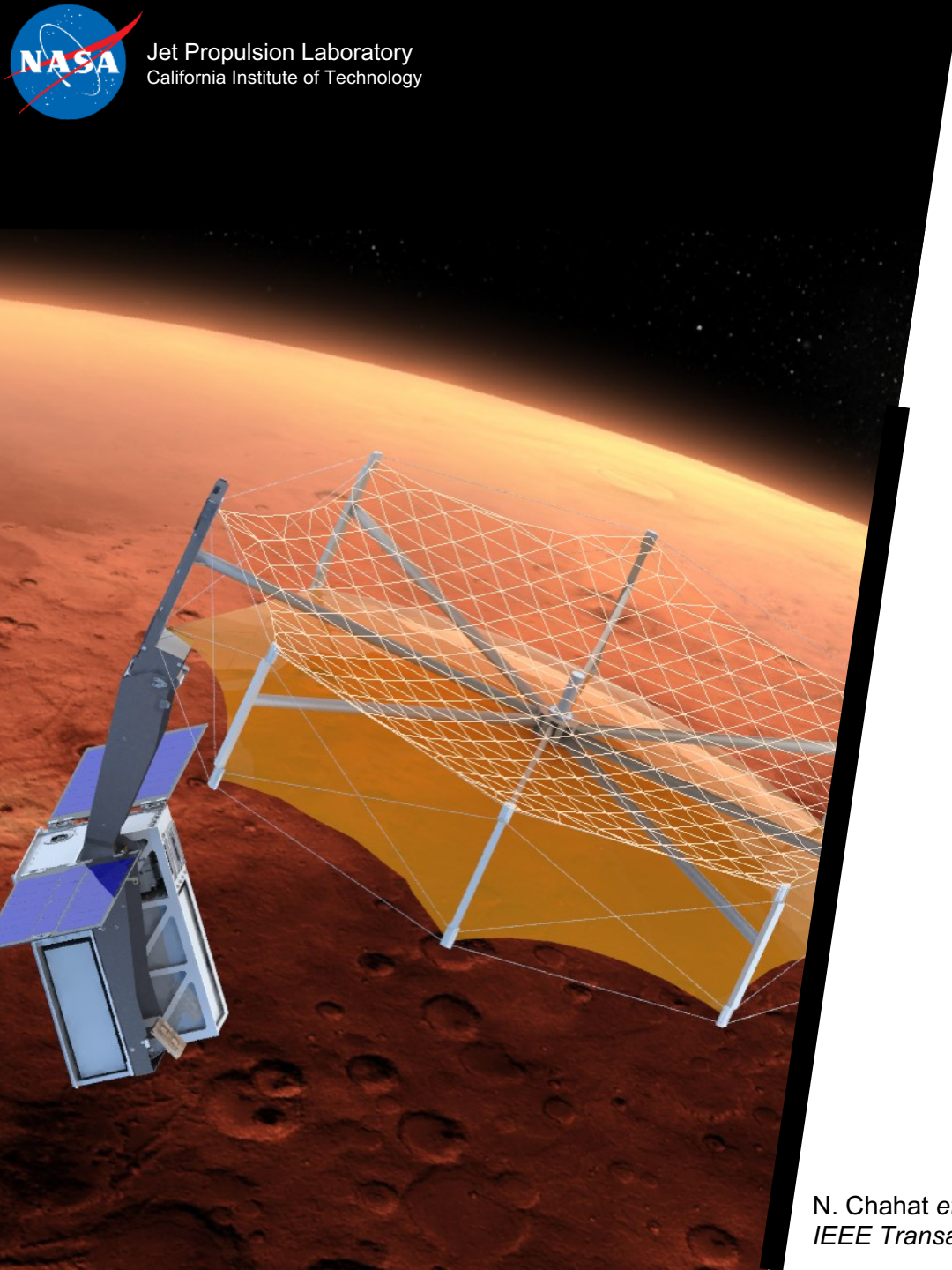
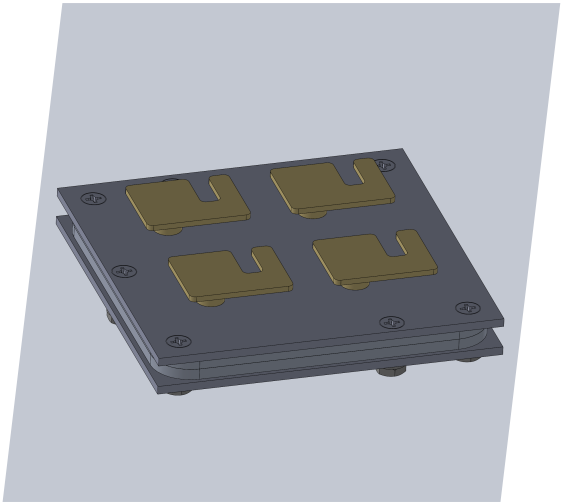
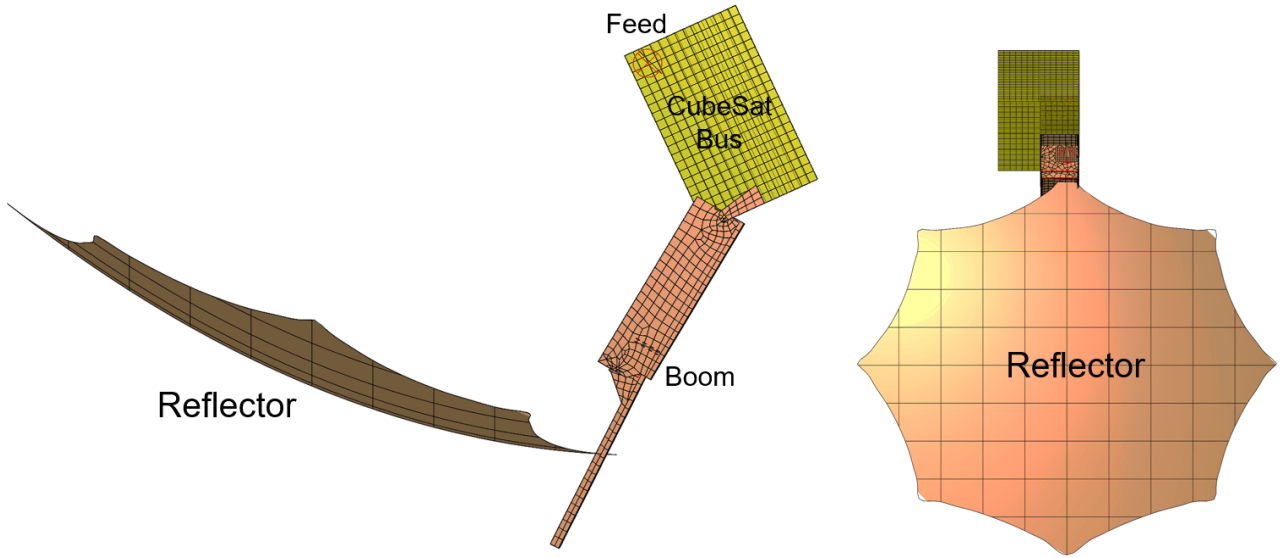


# X/Ka Deployable Mesh Reflector

**Feed at X-band**



**Feed at Ka-band**

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# X/Ka Deployable Mesh Reflector

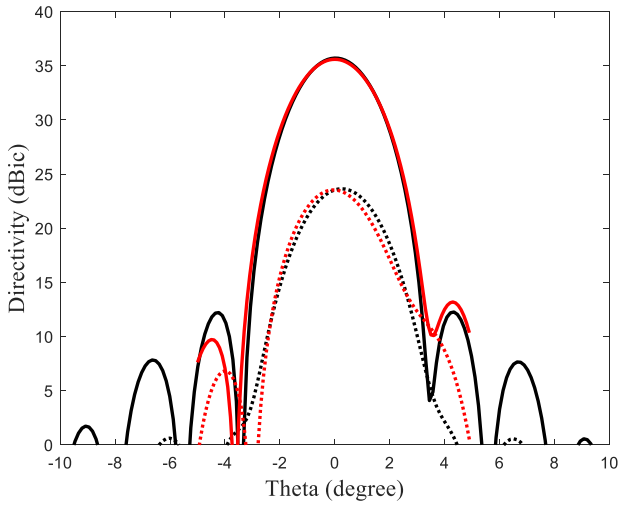
### *Gain Table at X-band*

| | Uplink | | Downlink | |
|---|---|---|---|---|
| | Gain (dBic) | Loss (dB) | Gain (dBic) | Loss (dB) |
| **Standard directivity** | 37.5 | - | 38.9 | - |
| **Taper** | 37.2 | 0.3 | 38.4 | 0.5 |
| **Spillover** | 36.3 | 0.9 | 37.4 | 1.0 |
| **Surface mesh* (30OPI)** | 36.28 | 0.02 | 37.38 | 0.02 |
| **Surface accuracy** (±0.38mm)** | 36.22 | 0.06 | 37.30 | 0.08 |
| **Feed loss** | 35.92 | 0.3 | 37.00 | 0.3 |
| **Feed mismatch (RL=15dB)** | 35.82 | 0.1 | 36.90 | 0.1 |
| **Overall performance** | 35.82 | 1.68 | 36.90 | 2.00 |

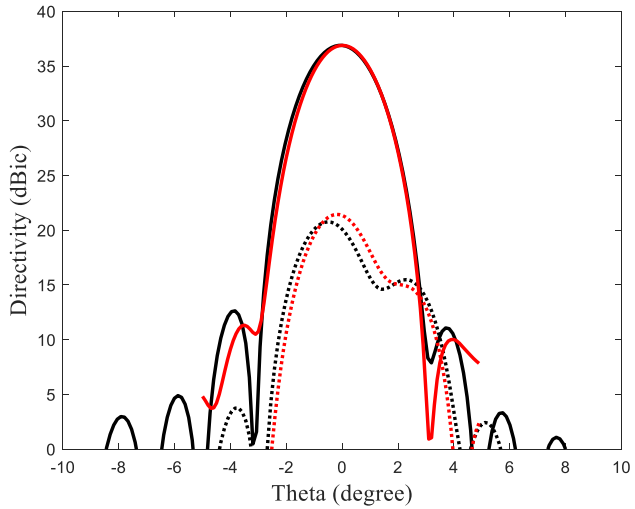
### *Calculated and measured performance*

| Freq. (GHz) | Directivity (dBi) | | Gain (dBic) | | Efficiency (%) | |
|---|---|---|---|---|---|---|
| | Calc. | Meas. | Calc. | Meas. | Calc. | Meas. |
| **7.1675** | 36.3 | 36.9 | 35.8 | 36.1 | 68 | 72 |
| **8.425** | 37.4 | 38.2 | 36.9 | 36.8 | 64 | 62 |

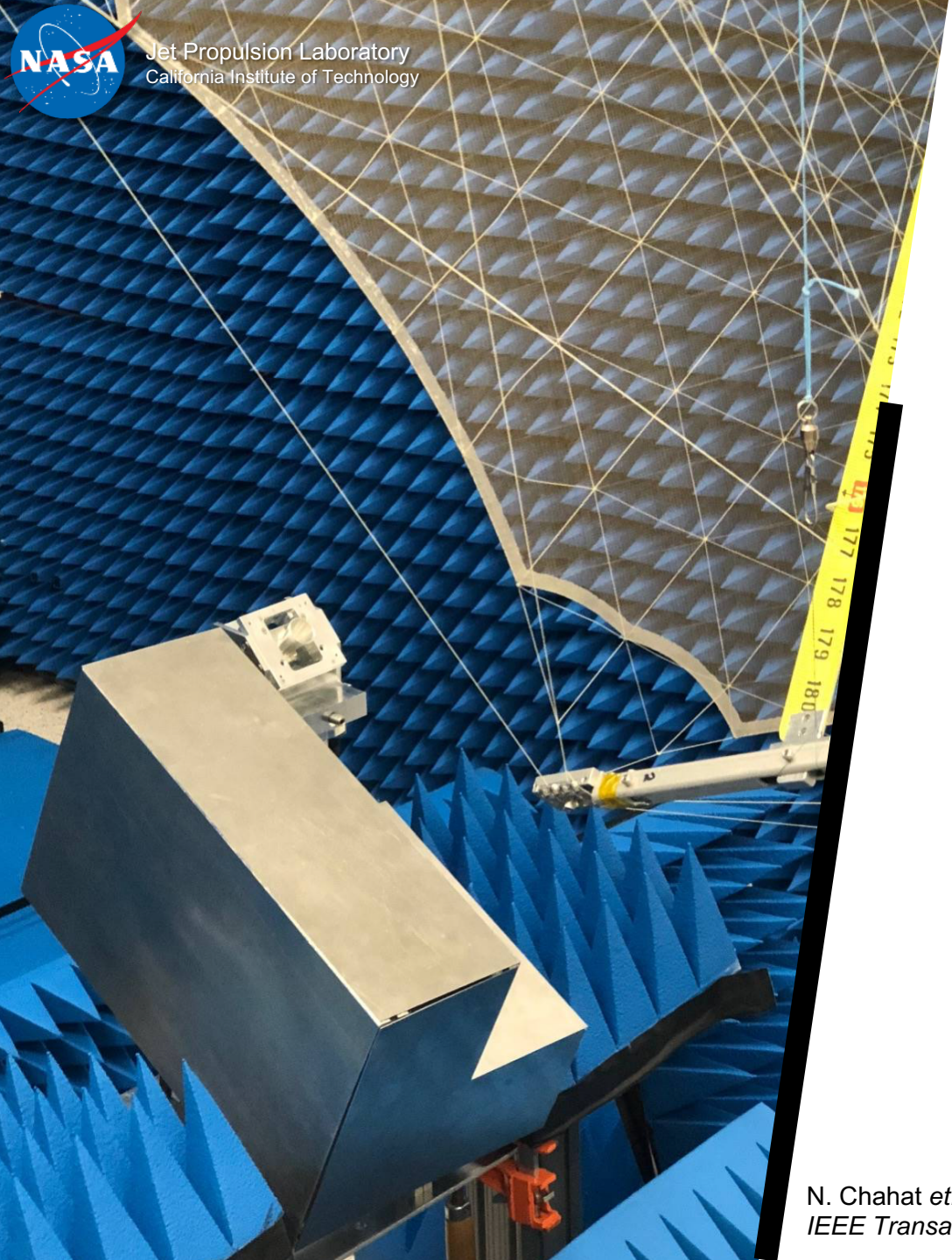
### *Uplink*




### *Downlink*




N. Chahat *et. al*, "One-Meter Deployable Mesh Reflector for Deep Space Network Telecommunication at X- and Ka-band," in *IEEE Transactions on Antennas and Propagation*.



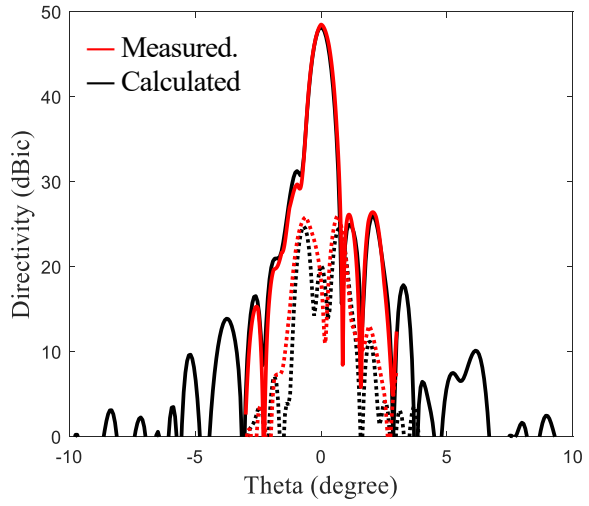

# X/Ka Deployable Mesh Reflector

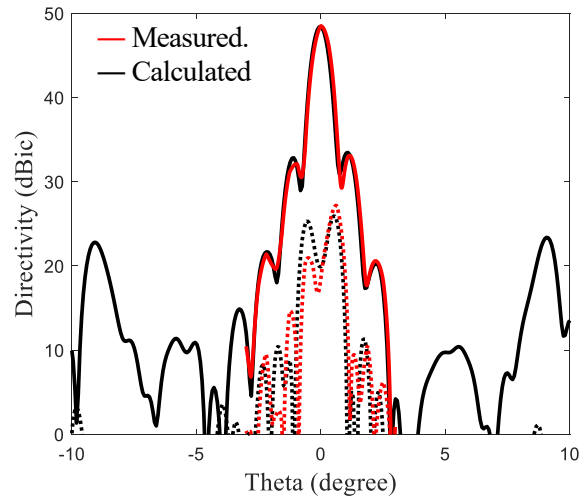
### *Gain Table at X-band*

| | Gain (dBic) | Loss (dB) |
|---|---|---|
| **Standard directivity** | 50.5 | - |
| **Taper** | 49.9 | 0.6 |
| **Spillover** | 49.5 | 0.4 |
| **Surface mesh* (30OPI)** | 49.25 | 0.25 |
| **Surface accuracy** (±0.38mm)** | 48.15 | 1.1 |
| **Feed loss** | 48.10 | 0.05 |
| **Feed mismatch (RL=15dB)** | 48.05 | 0.05 |
| **Overall performance** | 48.05 | 2.45 |

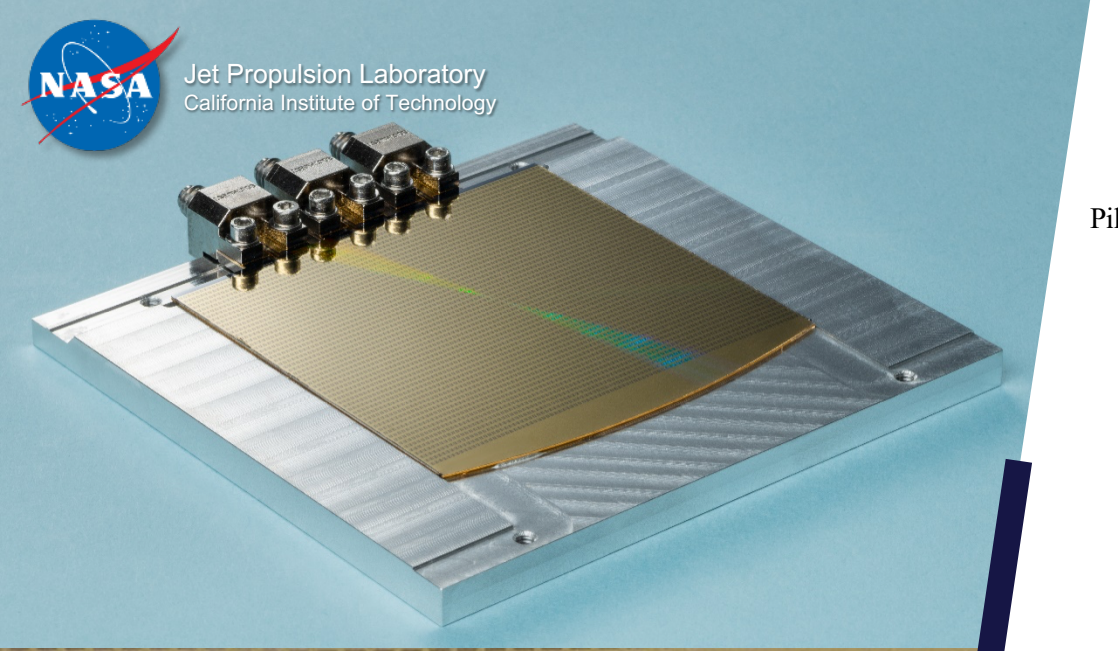
### *Calculated and measured performance*

| | Directivity (dBi) | | Gain (dBic) | | Efficiency (%) | |
|---|---|---|---|---|---|---|
| **Frequency (GHz)** | Calc. | Meas. | Calc. | Meas. | Calc. | Meas. |
| **32** | 48.4 | 48.8 | 48.1 | 48.4 | 58 | 62 |
| **34.45** | 48.5 | 49.0 | 48.3 | 48.7 | 52 | 57 |




N. Chahat *et. al*, "One-Meter Deployable Mesh Reflector for Deep Space Network Telecommunication at X- and Ka-band," in *IEEE Transactions on Antennas and Propagation*.

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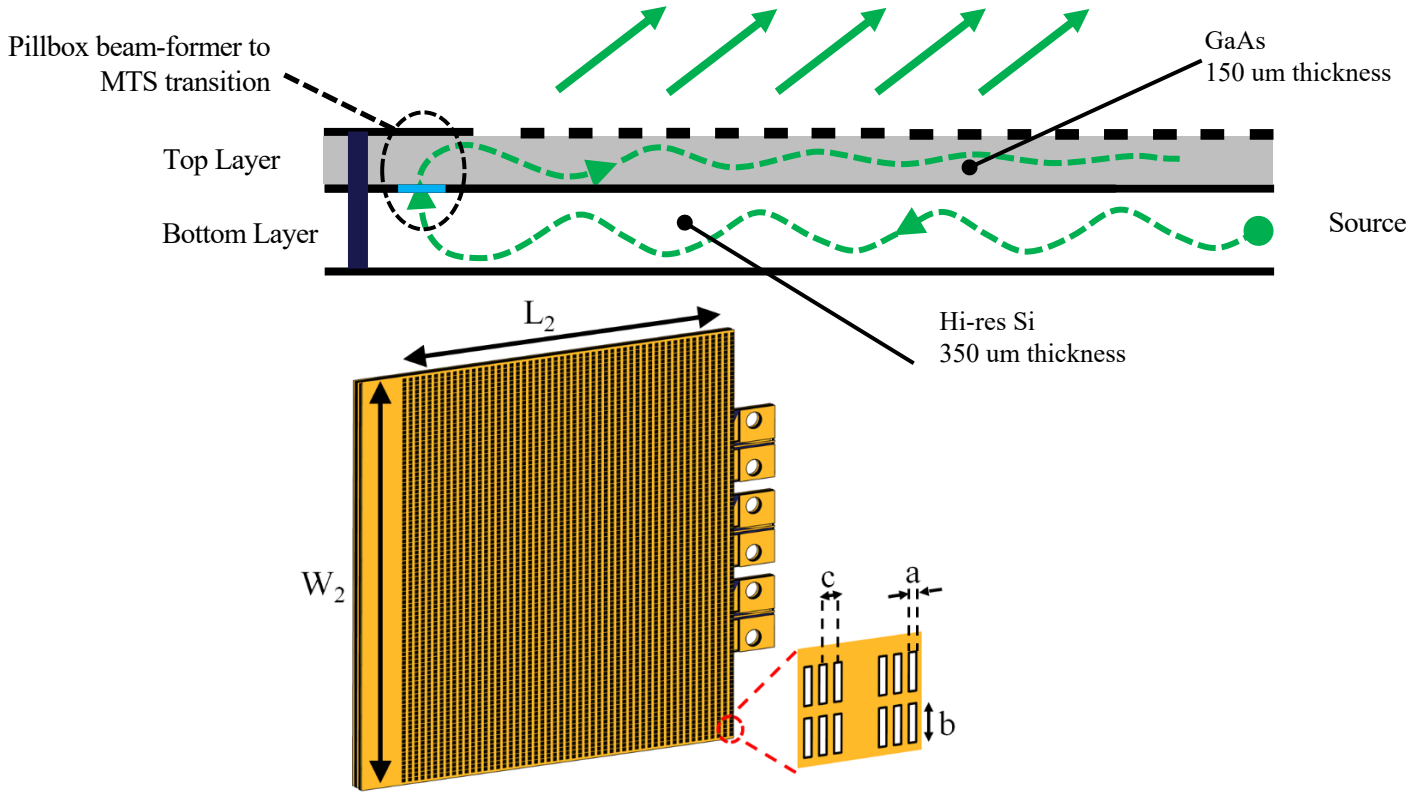
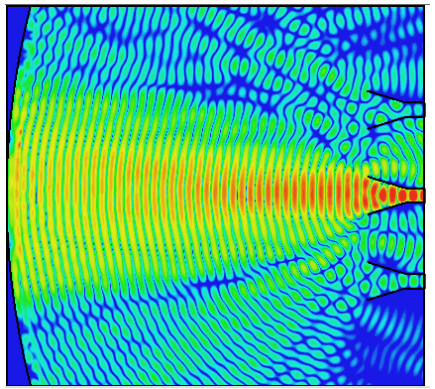
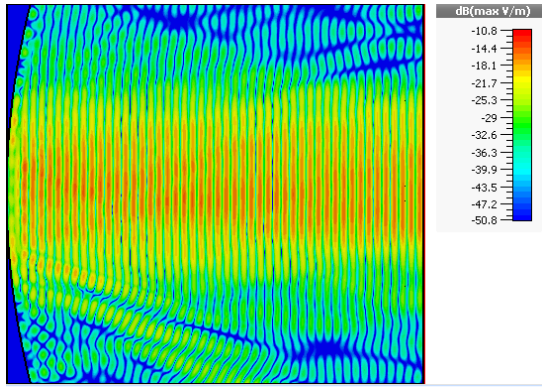



***E-Field (Silicon Layer)***



***E-Field (GaAs Layer)***



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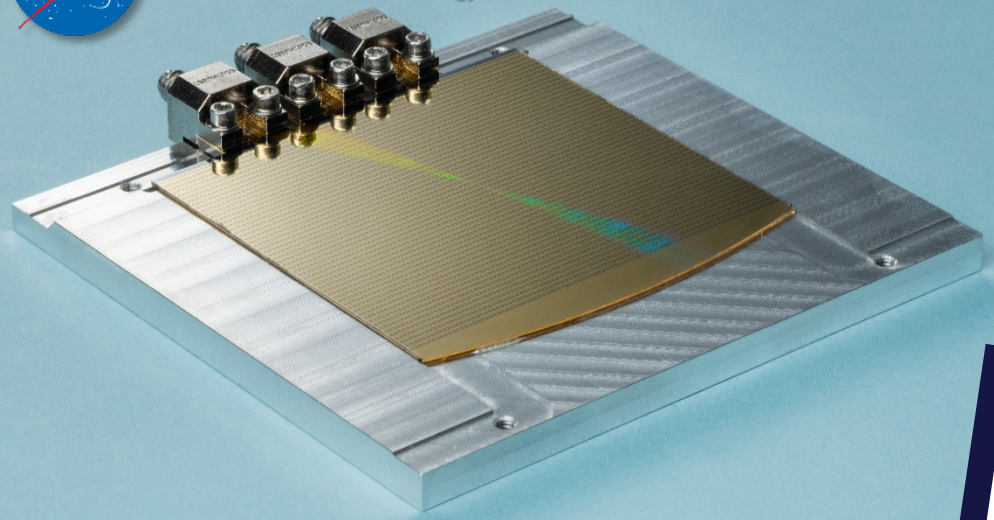
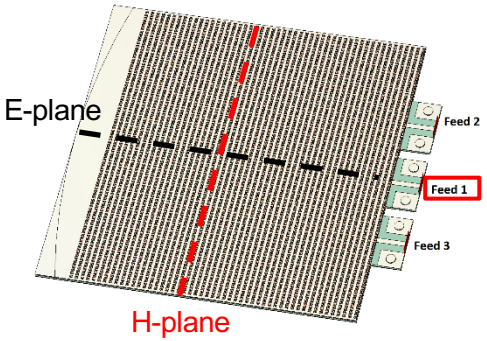
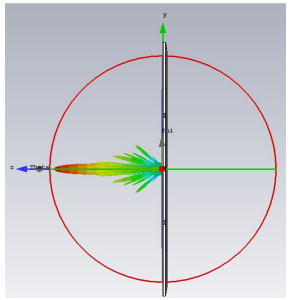
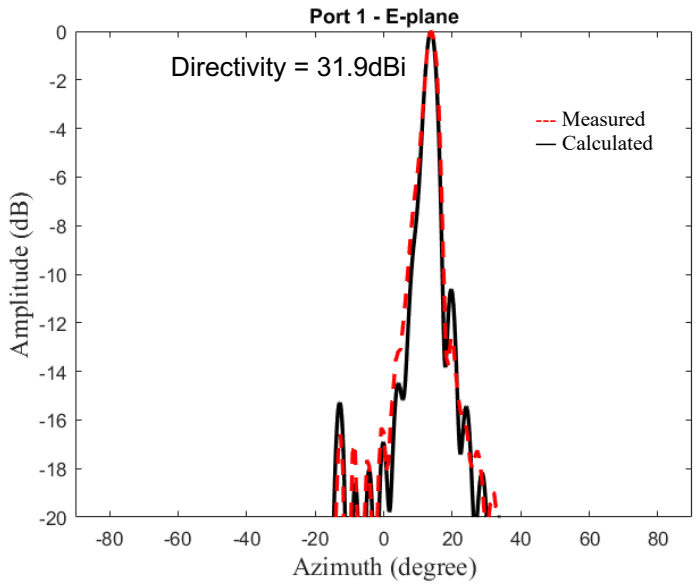


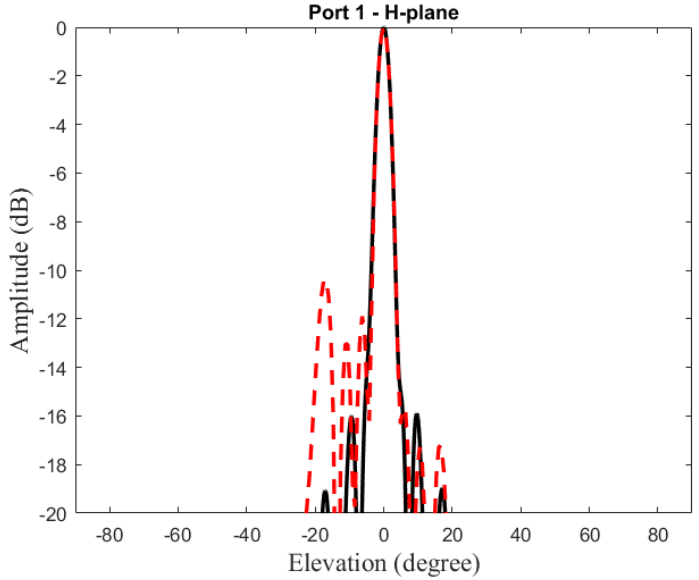
# Metasurface Antennas – The Future is Flat




Feed 1 for $\varphi$=0°





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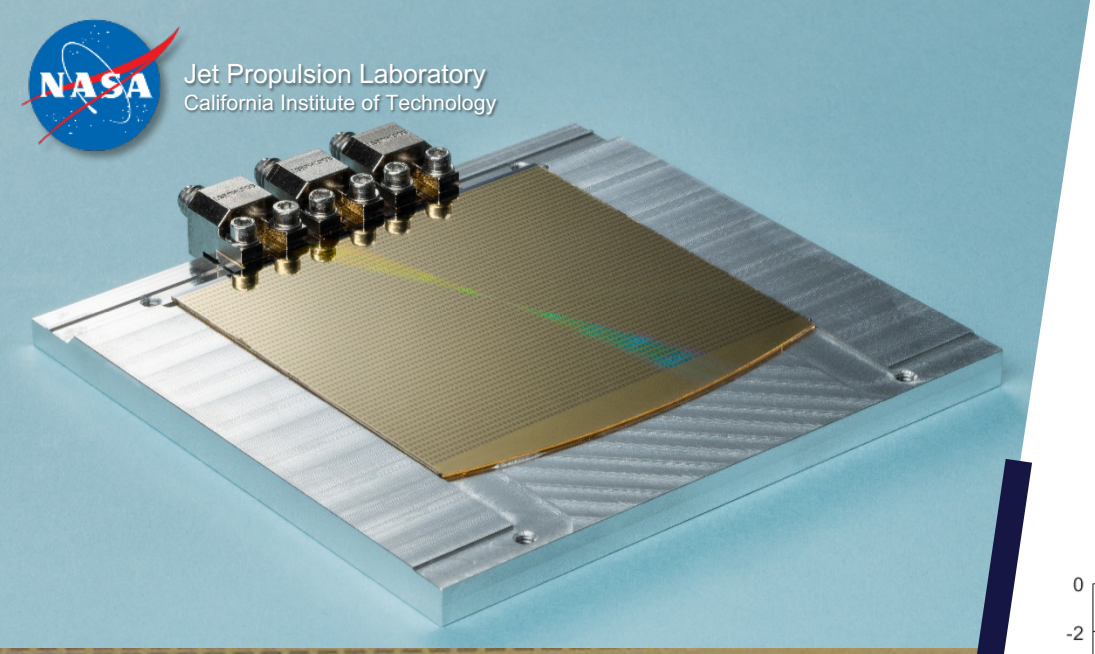
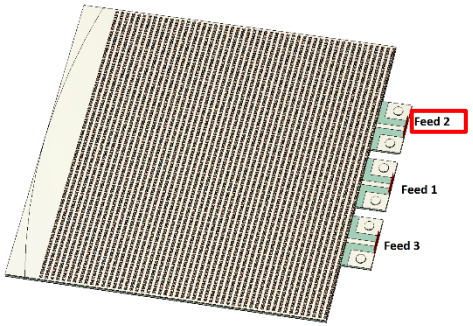
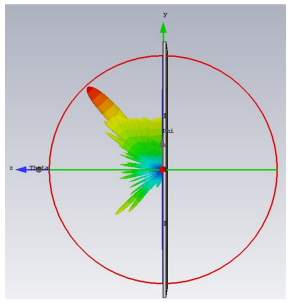
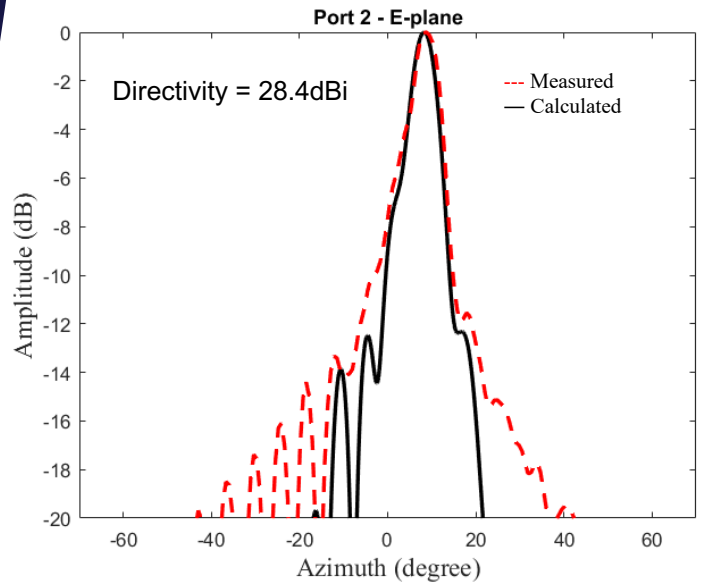
# Metasurface Antennas – The Future is Flat

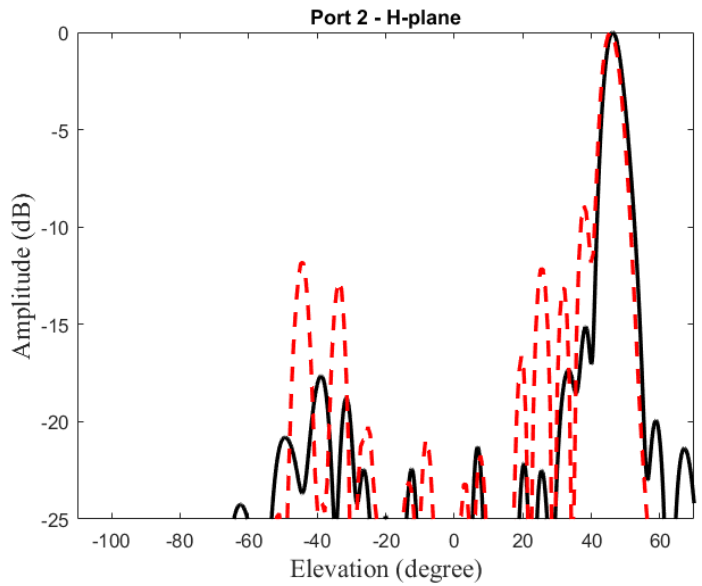


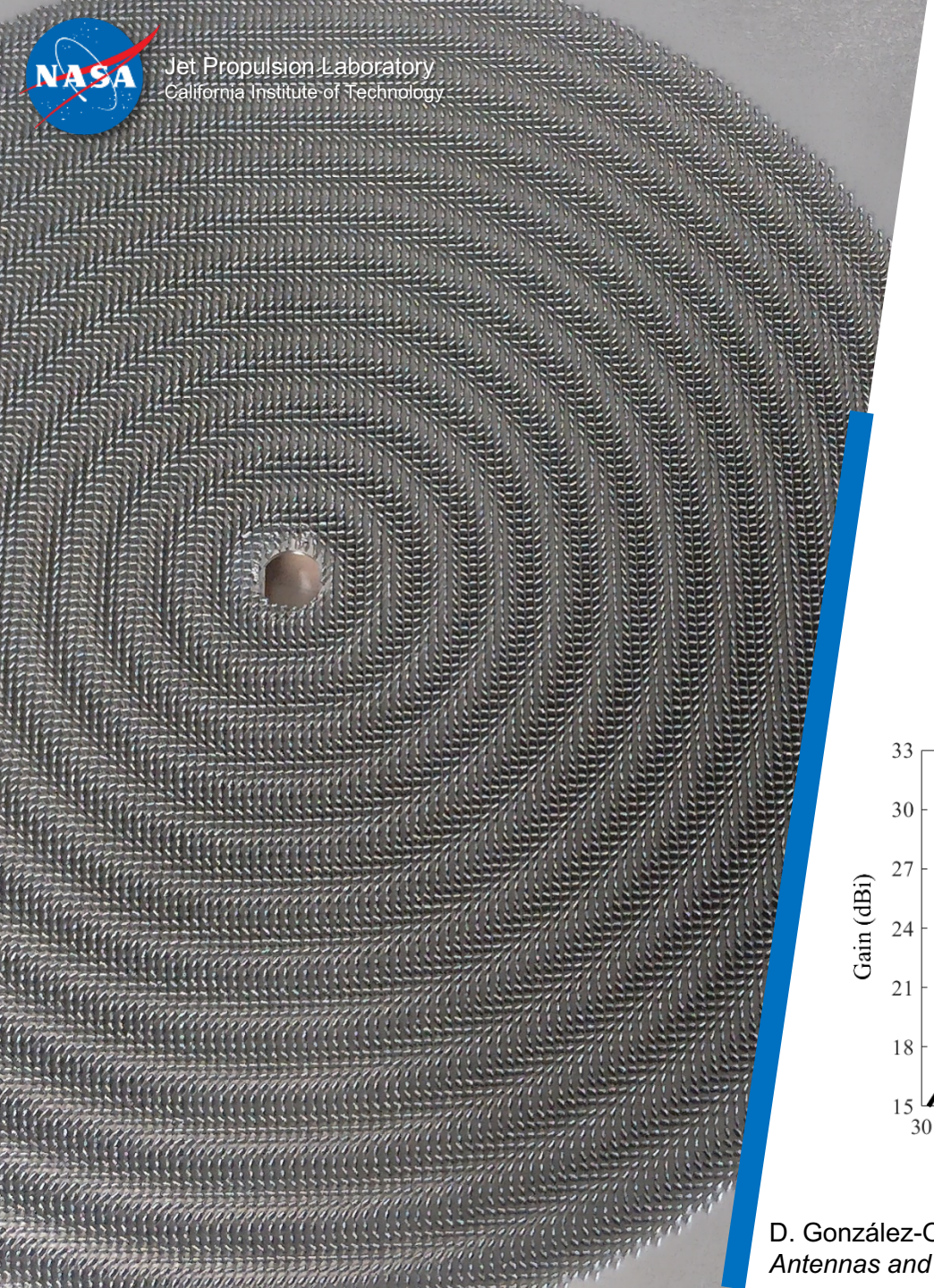



Feed 2 for $\varphi$=45°







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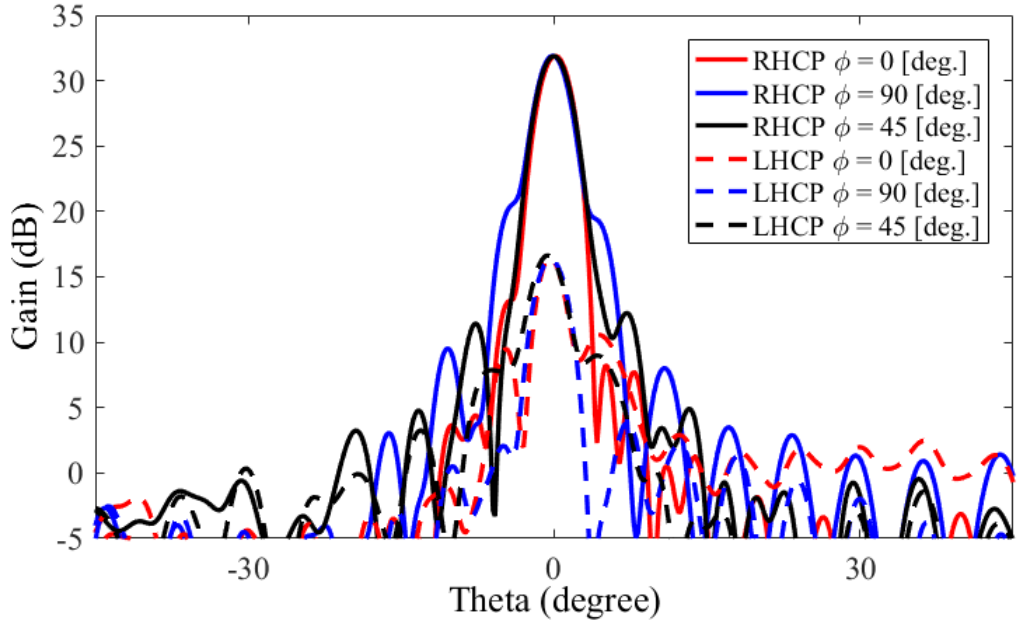


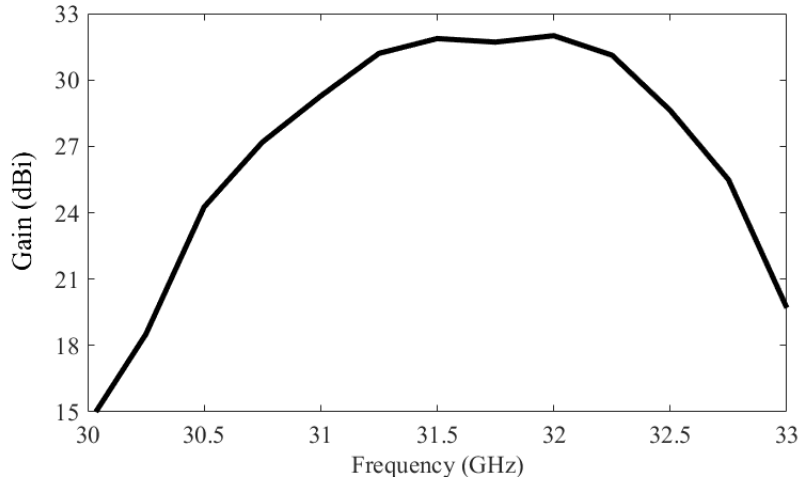


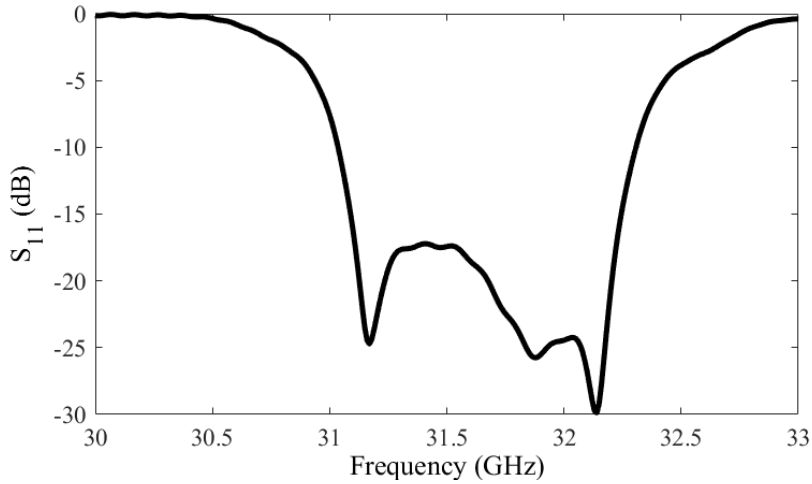


D. González-Ovejero *et al.*, "Additive Manufactured Metal-Only Modulated Metasurface Antennas," in *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 11, pp. 6106-6114, Nov. 2018.

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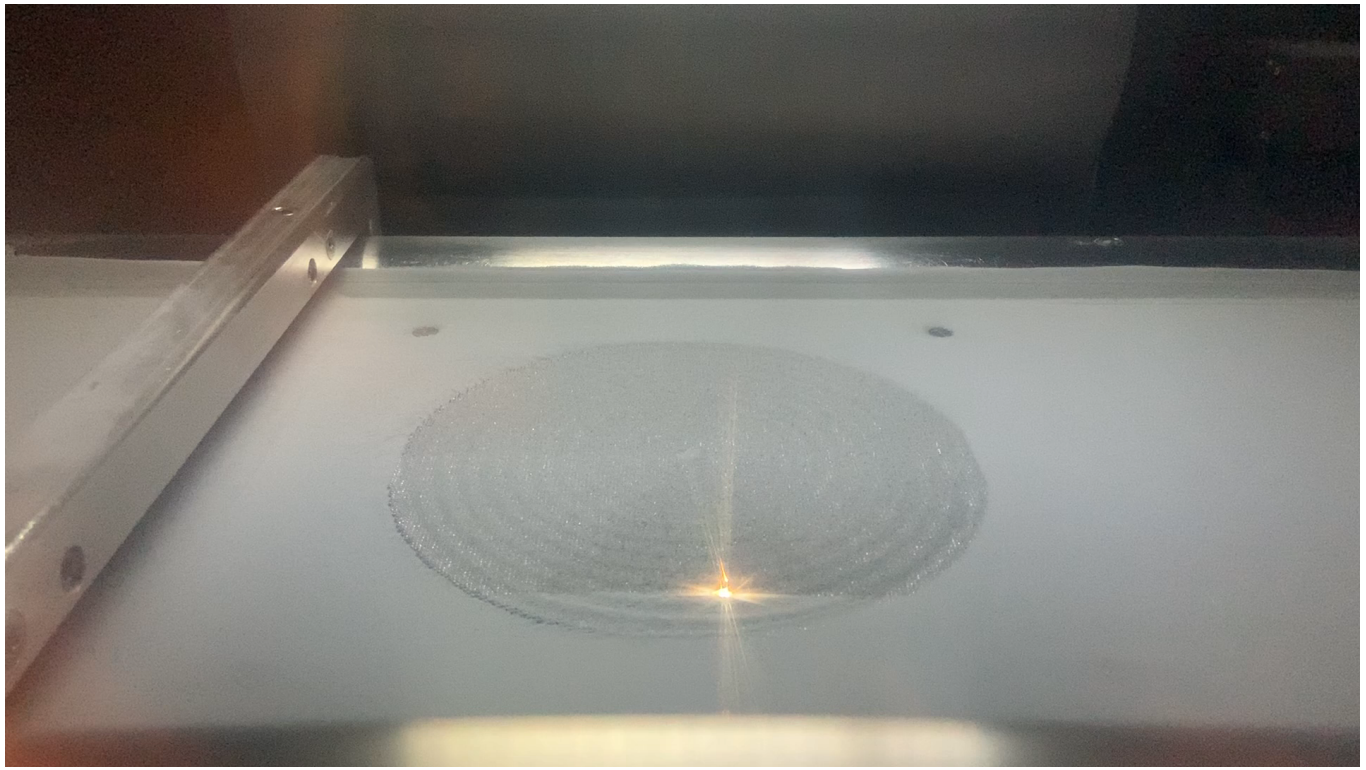
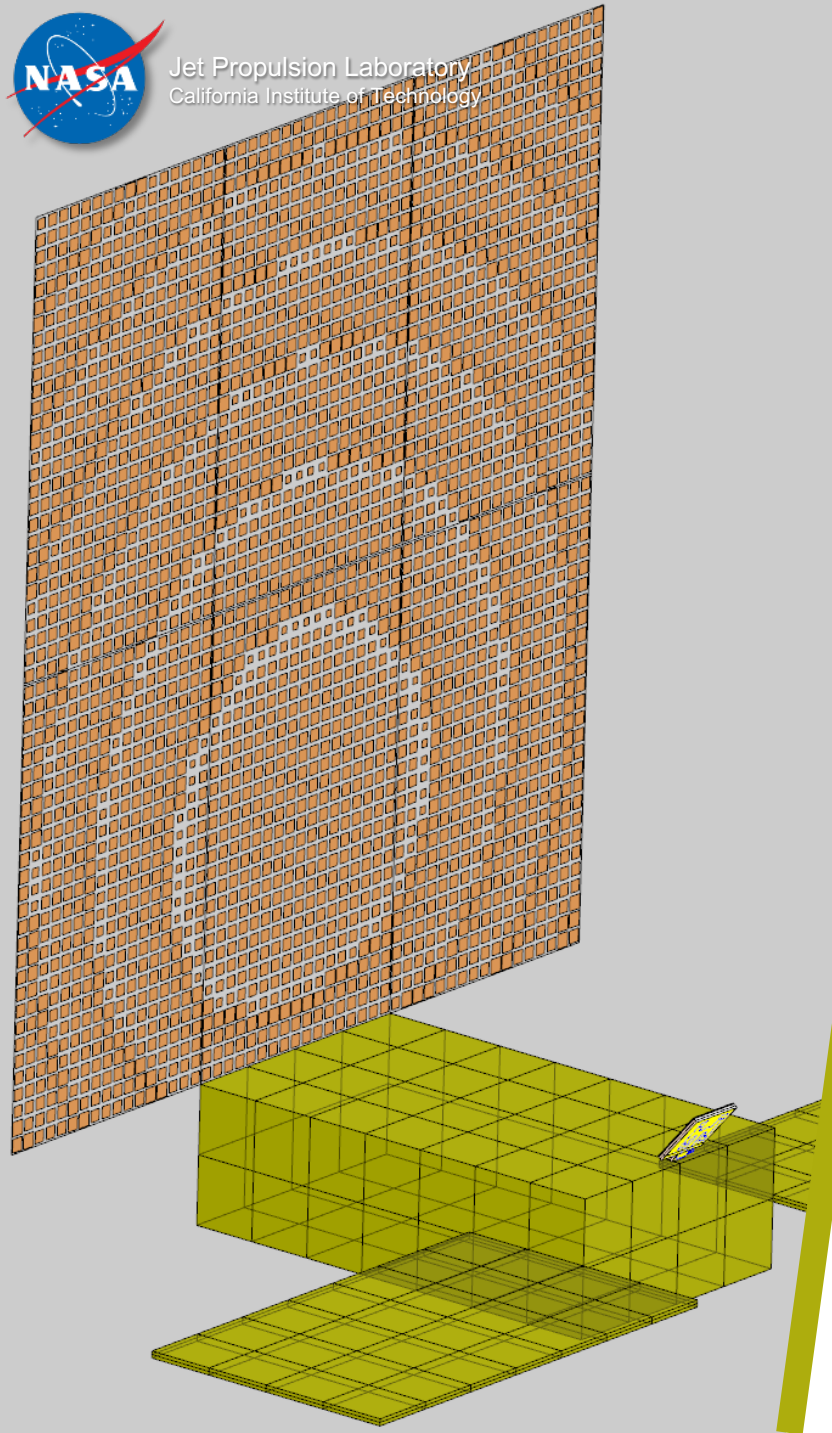
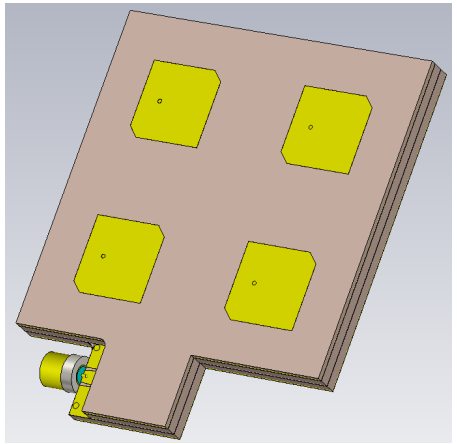


D. González-Ovejero *et al.*, "Additive Manufactured Metal-Only Modulated Metasurface Antennas," in *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 11, pp. 6106-6114, Nov. 2018.

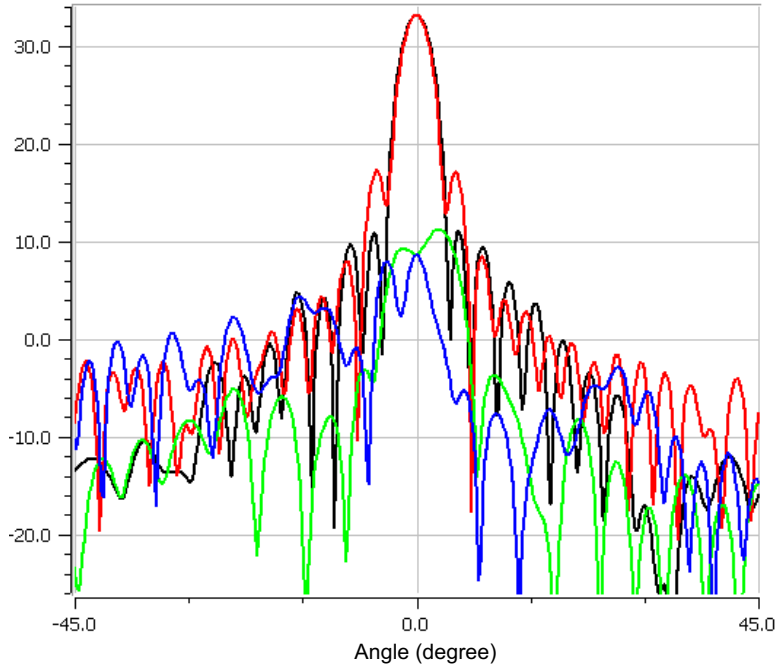


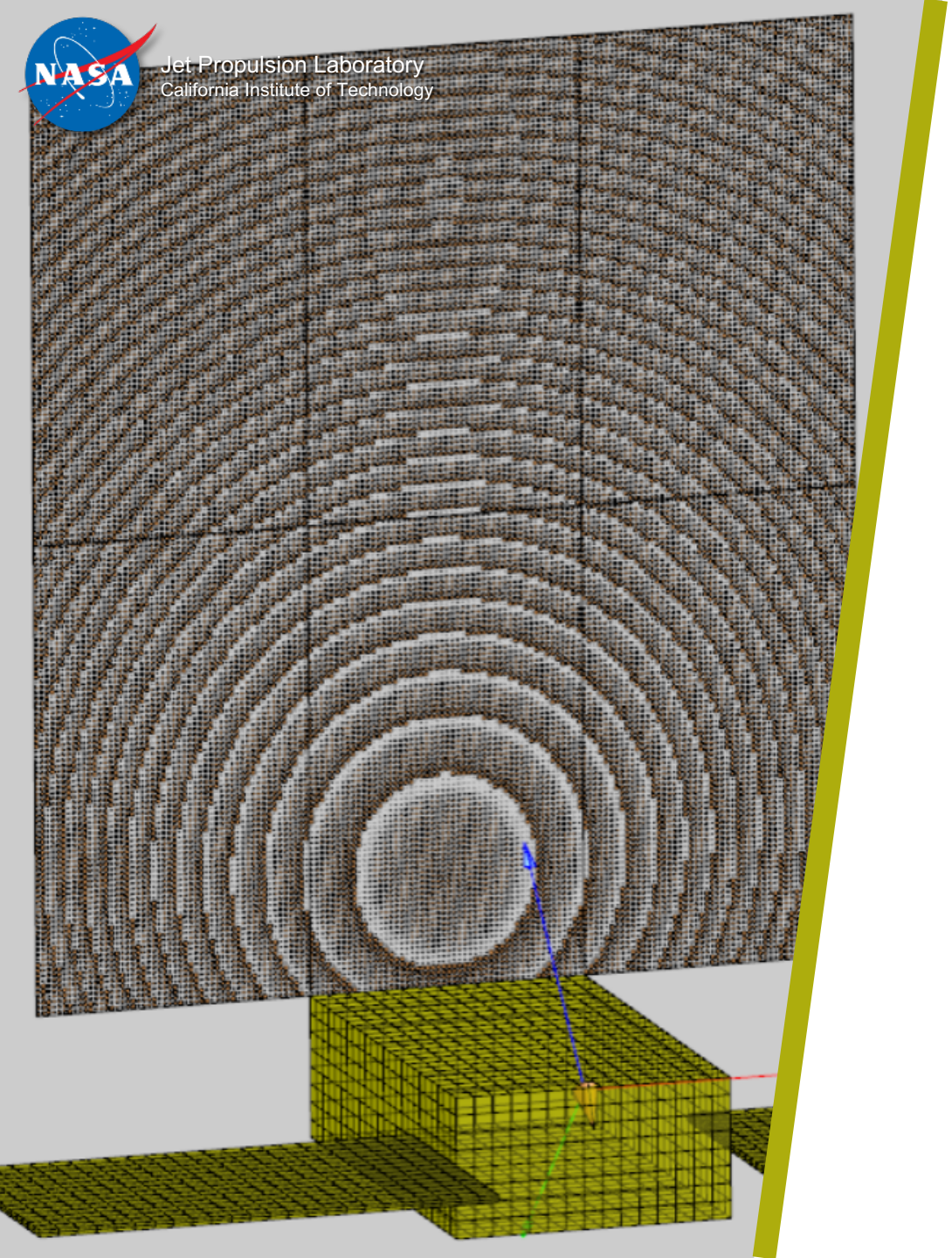
# More Reflectarrays – X-band

- **Features:**
  - Compatible with 6U CubeSat
  - X-band design for Telecom
  - Transmit only
  - Deployed area: 600mm × 670mm
  - Gain of 33.0dBic between 8.4-8.45GHz



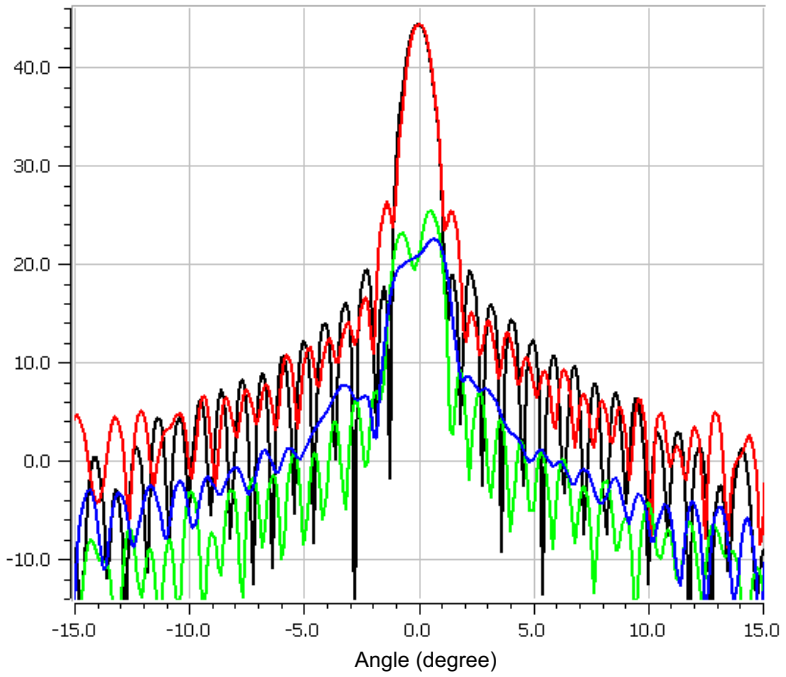
***Feed with MarCO heritage***

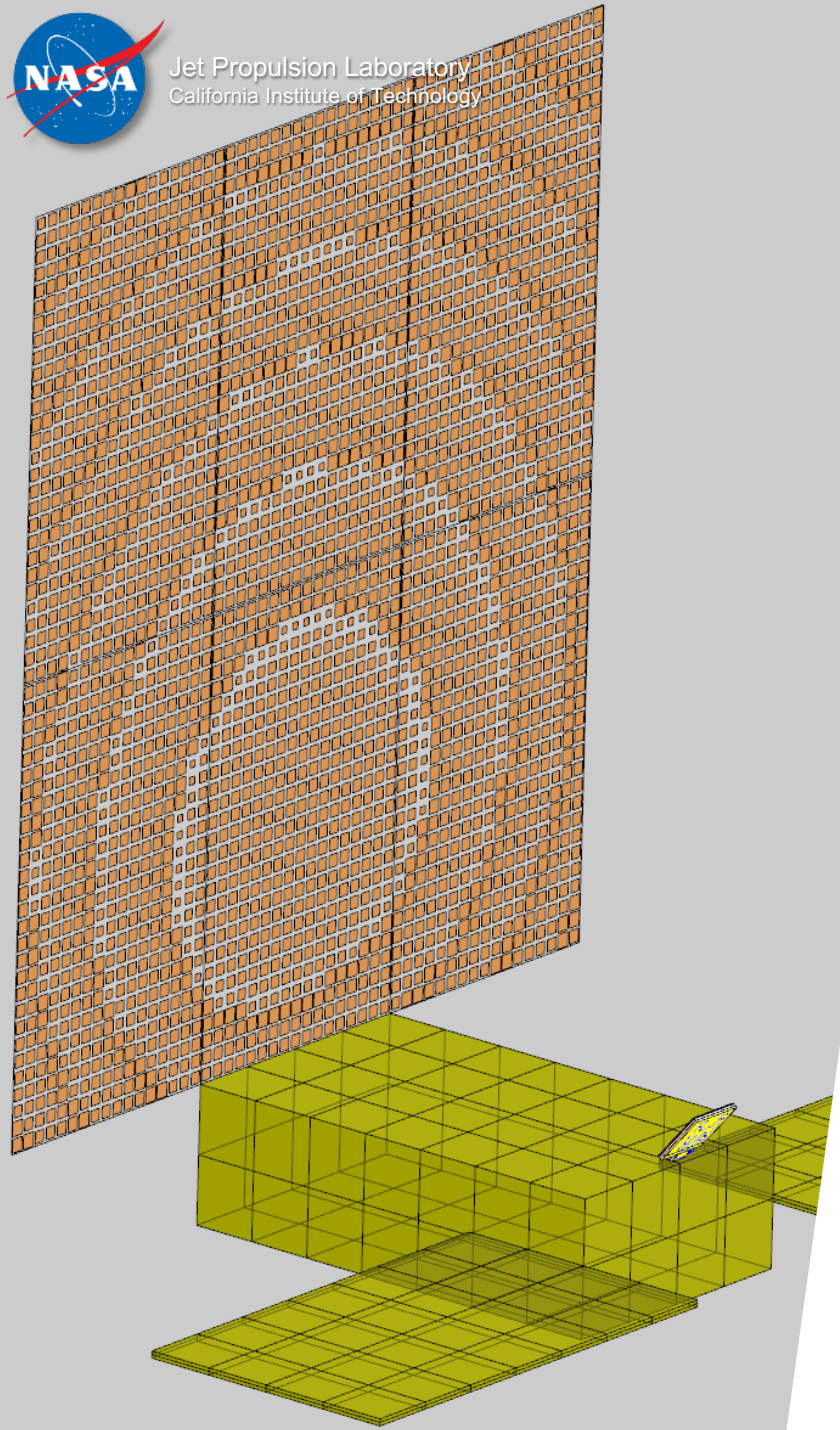





# More Reflectarrays – Ka-band

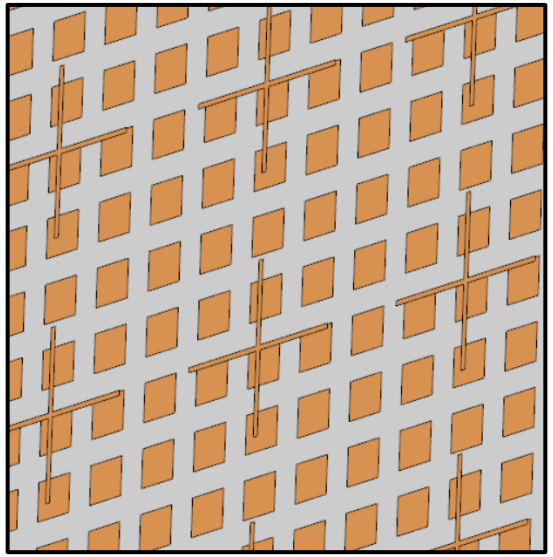
- **Features:**
  - Compatible with 6U CubeSat
  - Ka-band design for Telecom
  - Transmit only
  - Deployed area: 600mm × 670mm
  - Gain of 44.0dBic between 31.8-32.3GHz

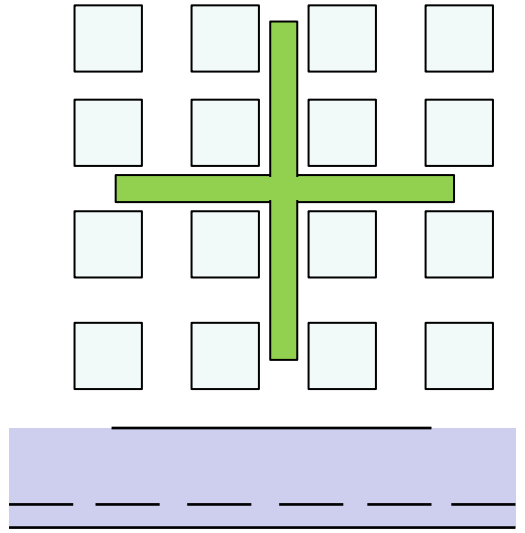




# More Reflectarrays – X/Ka-band

- **Features:**
  - Compatible with 6U CubeSat
  - X- and Ka-band design for Telecom
  - Transmit only
  - Deployed area: 600mm × 670mm
  - Gain of 32dBic between 8.4-8.45GHz
  - Gain of 43.5.0dBic between 31.8-32.3GHz
  - Co-located feed with identical beam-pointing





*X-band elements in green ($h_X$=1.5mm)*
*Ka-band elements in blue ($h_{Ka}$=0.406mm)*

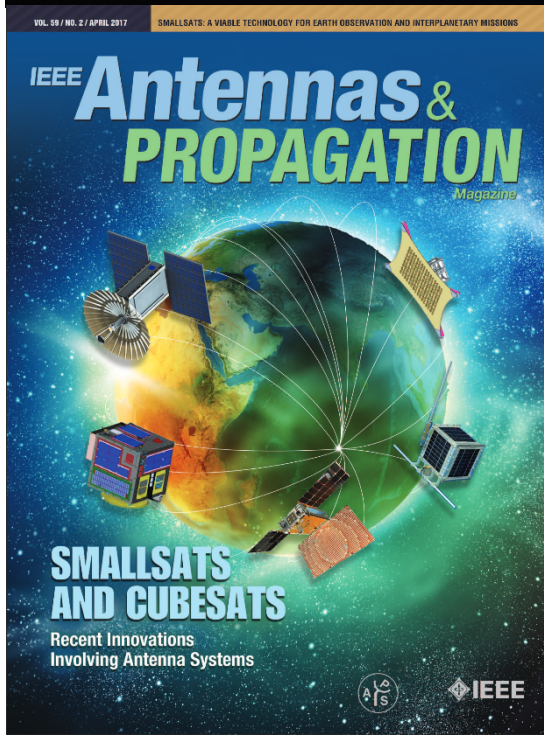
## REFERENCES - JOURNALS

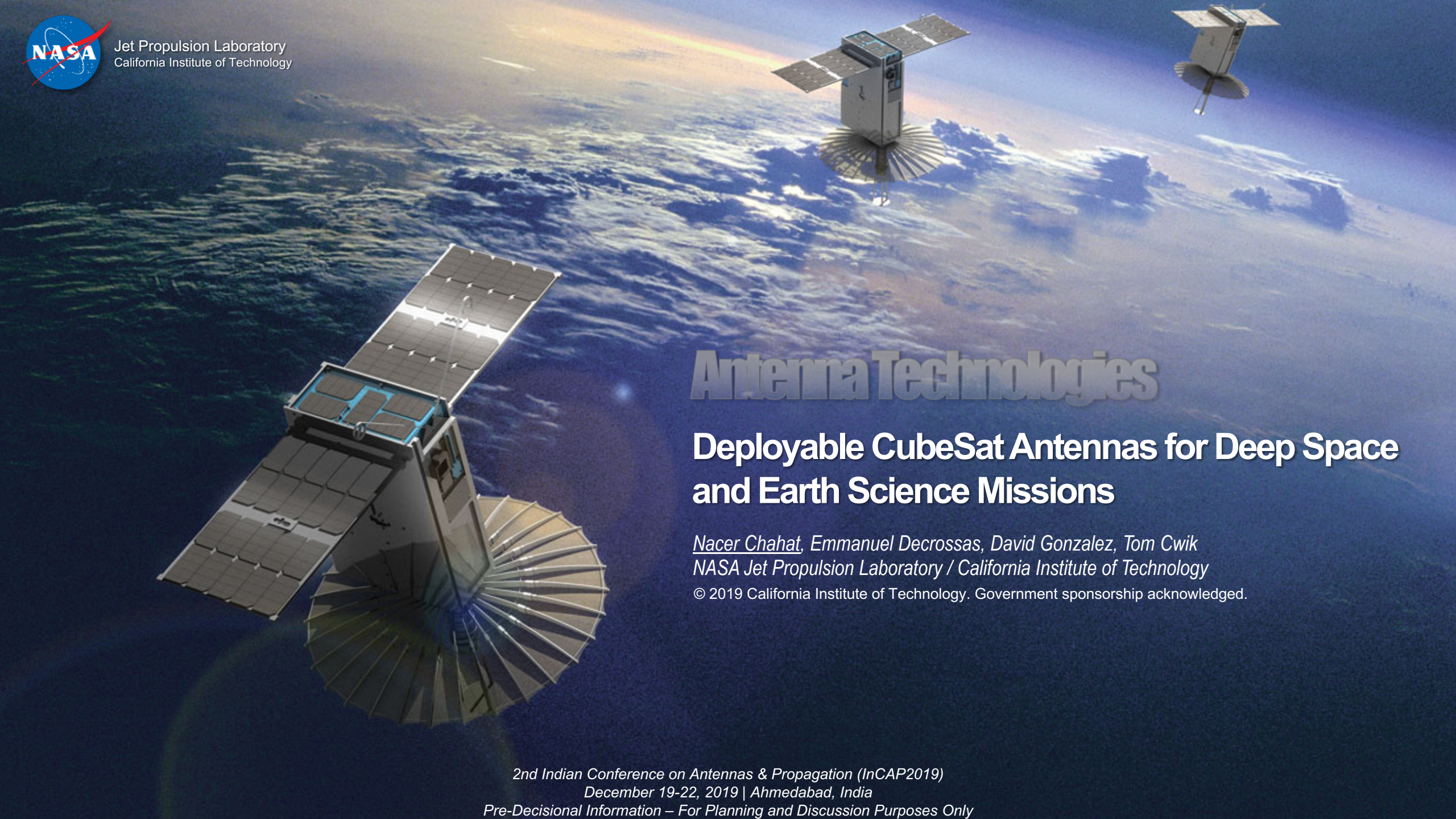

- N. Chahat *et al.*, "One-Meter Deployable Mesh Reflector for Deep Space Network Telecommunication at X- and Ka-band," in *IEEE Transactions on Antennas and Propagation*.
- N. Chahat *et al*., "Advanced CubeSat Antennas for Deep Space and Earth Science Missions: A review," in *IEEE Antennas and Propagation Magazine*, vol. 61, no. 5, pp. 37-46, Oct. 2019.
- T. Cwik *et al.*, “Deployable reflectarray antenna,” US Patent #10,276,926 B2, Issue date on 4/30/2019.
- N. Chahat *et al.*, "All-Metal Dual-Frequency RHCP High-Gain Antenna for a Potential Europa Lander," in *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 12, pp. 6791-6798, Dec. 2018.
- D. González-Ovejero *et al.*, "Additive Manufactured Metal-Only Modulated Metasurface Antennas," IEEE Transactions on Antennas and Propagation, vol. 66, no. 11, pp. 6106-6114, Nov. 2018.
- N. Chahat, “A mighty antenna from a tiny CubeSat grows,” *IEEE Spectrum*, vol. 55, no. 2, pp. 32-37, Jan. 2018.
- N. Chahat *et al.*, “The Deep Space Network Telecommunication CubeSat Antenna: Using the deployable Ka-band mesh reflector antenna,” IEEE Antenna Propag. Magazine, vol. 4, April 2016.
- N. Chahat *et al.*, "CubeSat Deployable Ka-Band Mesh Reflector Antenna Development for Earth Science Missions," *IEEE Trans. Antennas & Propag.*, vol. 64, no. 6, pp. 2083-2093, June 2016.
- R. E. Hodges *et al.*, “A Deployable High-Gain Antenna Bound for Mars: Developing a new folded-panel reflectarray for the first CubeSat mission to Mars,” IEEE Antenna Propag. Magazine, vol. 4, April 2016.


## REFERENCES - BOOK


- N. Chahat, “CubeSat Antennas for Earth Science and Interplanetary missions”, *Wiley / IEEE Press*, In Press, 2020.








# Deployable CubeSat Antennas for Deep Space and Earth Science Missions

*Nacer Chahat, Emmanuel Decrossas, David Gonzalez, Tom Cwik*
*NASA Jet Propulsion Laboratory / California Institute of Technology*

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